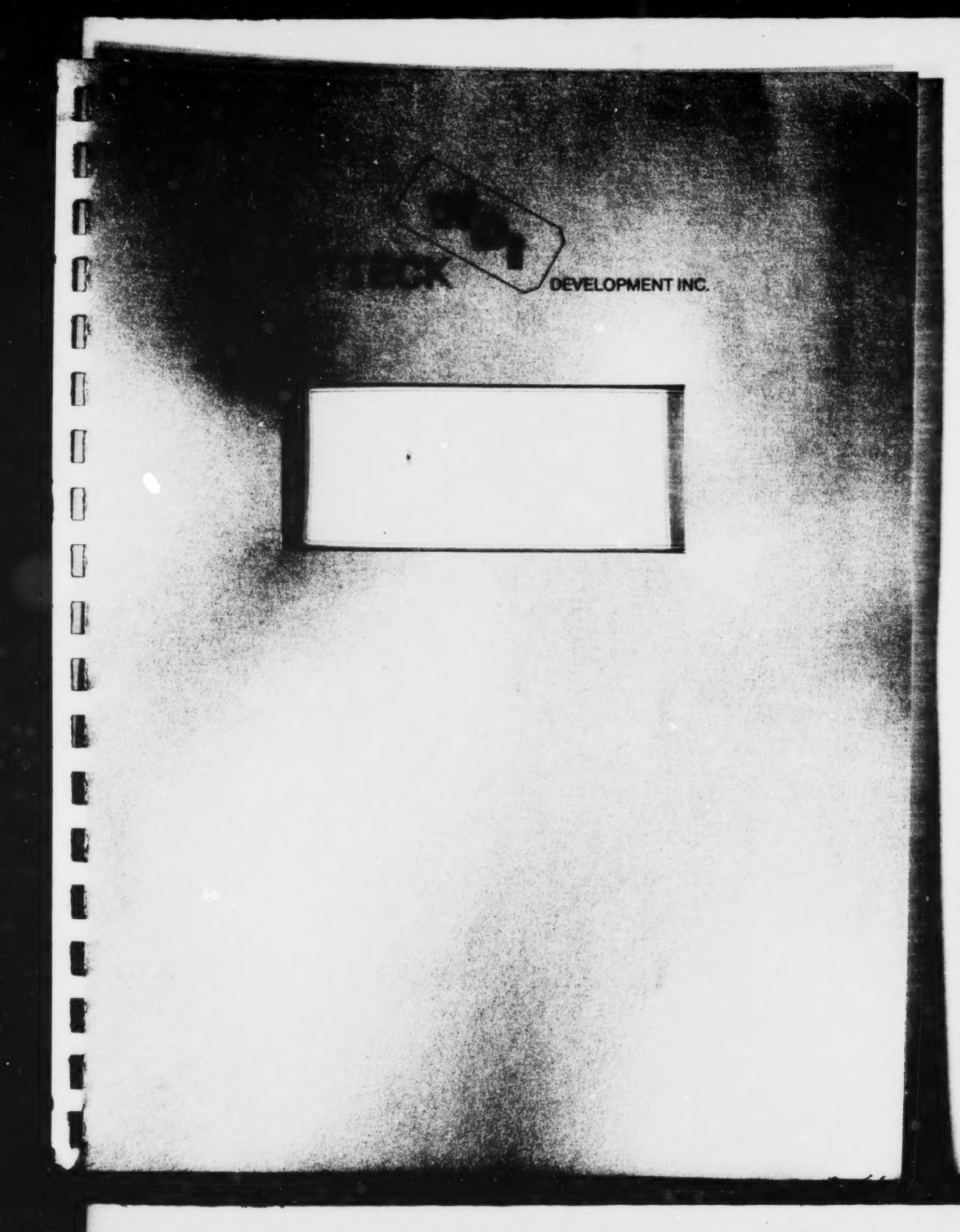
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EVALUATION OF RESIN-IN-PULP TECHNOLOGY FOR CANADIAN GOLD ORES

Project No. 5151

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1.0 SUMMARY

The following paper reports on the results of Phase I of a three phase test and feasibility study entitled "The Evaluation Resin-in-Pulp Technology for Canadian Gold Ores" (DSS Contract 15SQ.23440-6-9053).

Phase I included:

1) A comprehensive literature survey;

2) procurement of authentic cyanidation leach slurry from a Canadian gold milling operation;

3) liaison with the resin manufacturers to obtain samples of a wide variety of resins for testing;

4) bench scale testwork to evaluate the various resins for gold recovery, including adsorption and elution data for gold and base metals;

5) a 90 hour mini-plant campaign for flowsheet optimization and to obtain information on resin/pulp separation, resin attrition, resin scaling and poisoning and stage requirements.

Witteck Development was successful in obtaining authentic samples of both gold ore and gold-bearing cyanidation leach slurry for the resin-in-pulp bench scale testwork and the mini-plant campaign. The initial benchscale loading testwork was performed on pregnant cyanidation leach solutions. The most promising resins were then reinvestigated using cyanidation leach slurries. Loading capacities and barren levels were determined for gold, as well as antimony, arsenic, copper, iron, silver and zinc.

In total, seven resins were investigated during Phase I. A weak base, high pKa macroporous experimental resin supplied by Dow Chemical proved to be the most promising. This Dow resin, XU-40114.00, demonstrated a selectivity for gold adsorption over most of the common base metals. Only zinc was found to load on to the resin to any extent during the bench scale test program. Gold loadings reached 17.8 kg Au/t (519 oz/ton) of resin from a 45% solids cyanidation leach slurry.

Furthermore, elution was achieved using the Zadra (17) method for carbon desorption, facilitating the potential conversion of carbon stripping facilities to resin stripping. Both gold and zinc were recovered quantitatively in the eluate, within experimental error.

A 90 hour mini-plant campaign was included in Phase I. Four stages of resin-in-pulp were sufficient to remove gold from the pulp filtrate to below the detection limit (< 0.03 ppm by DCP). Gold loadings of 10.5 kg Au/t (306 oz/ton) of resin were achieved from a 41% solids cyanidation leach pulp which assayed 3.51 ppm Au and 0.77 ppm Zn.

Scanning electron microscopy was used to compare the resin removed from the RIP circuit after the 90 hour campaign to fresh resin. While a small amount of surface attrition was noted, a pilot scale operation is required to ascertain if the amount of attrition observed is simply the loss of surface powders from the smooth surface of the new resin, or if similar degrees of attrition would occur during subsequent hours of operation. No scaling of the resin was evident.

Resin/pulp separation was achieved manually by screening the slurry of a stage of the RIP circuit through a 40 mesh screen. While the separation was facile, continuous methods of resin/pulp separation will need to be investigated during the pilot scale campaign planned for Phase II of this test program.

Elution of the resin removed from stage 1 during resin advancement was undertaken using an eluant of 1% NaOH, 1% NaCN, at 90 to 93°C. An elution isotherm was produced; 94% of the gold was recovered within 15 bed volumes of eluate.

2.0 INTRODUCTION

Conventional technologies for gold recovery from cyanidation leach slurries include zinc precipitation and carbon-in-pulp or carbon-in-leach. Most of the recently discovered gold ore reserves in Canada contain free, finely dissemenated gold in a host mineral. Consequently, the liberation size is typically finer than 200 mesh. Therefore, these ores and concentrates, after conventional cyanidation, are natural candidates for a adsorption technology such as carbon-in-pulp (CIP) or resin-in-pulp (RIP) rather than the more conventional process involving liquid-solid separation followed by zinc precipitation.

Resins possess several characteristics which make them very attractive in comparison to carbon. However, while RIP has been investigated in South Africa, no work has been reported to date on Canadian gold ores. Since future gold developments in Canada will result in new processing plants, Witteck Development suggested that a comparison of resin-in-pulp to the widely used carbon-in-pulp process would be both valuable and timely.

Consequently, an unsolicited proposal was submitted to Canada Centre for Mineral and Energy Technology (DSS Contract 15SQ.23440-6-9053) by Witteck Development Inc. on March 11, 1985. The original proposal outlined a three phase test and feasibility program to evaluate fully resin-in-pulp technologies for Canadian gold ores. The program had been broken down into the following phases:

Phase I - Development of bench scale data to compare the RIP and CIP technologies.

Phase II - A pilot demonstration on the developed RIP technology using a representative sample of a typical Canadian gold ore.

Phase III - A feasibility study to compare the capital and operating cost of a conventional CIP plant to a RIP plant.

The work for Phase I has been completed and is reported herein.

3.0 BACKGROUND

The extraction of gold from cyanide solutions using synthetic anion exchange resins is an alternative to the use of activated carbon. A comparison of the resin-in-pulp (RIP) process to the widely used carbon-in-pulp (CIP) process would be valuable since resins have several characteristics which make them attractive in comparison to carbon. Some of the potential advantages of resins detailed in the literature are:

- anion exchange resins load aurocyanide faster, and to a higher equilibrium capacity than carbon;

- most resins can be eluted efficiently at room temperature, whereas the most efficient elution of carbon is at elevated temperatures and under pressure;

- resins do not load $CaCO_3$ to the same extent as activated carbon;

- resins are not poisoned by flotation reagents or organic solvents, all of which can inhibit the loading of gold onto activated carbon;

- the long term supply of activated carbon is questionable;

- the quality of carbon varies widely from one manufacturer to another, or from batch to batch since it is a natural sustance obtained from coconut shells. Synthetic resins would be more consistent due to quality control at the manufacturing level;

- resins may be used which extract all metals from solution, producing an environmentally acceptable waste effluent.

Some potential disadvantages of resin with respect to activated carbon detailed in the literature are:

- anion exchange resins studied to date are less selective than activated carbon for gold cyanide over other metal cyanide species. This requires either selective elution or electrowinning operations to separate the gold from the base metal cyanides;

- in CIP, the pulp is usually screened through 28 mesh, with a 20 mesh interstage screen. The maximum feasible mesh size for commercially available resins was approximately 35 mesh, with a 28 mesh interstage screening; (Note: larger mesh resins are now available)

- resins are less dense than activated carbon and tend to accumulate on the surface of the pulp, requiring a different type of agitator design to insure good mixing;

- the physical strength of resins with respect to attrition under agitation is largely unknown.

A brief description of the various classifications of resins is provided below.

3.1 Strong Base Resins

Aurocyanide and other metal anions are adsorbed onto strong base resins by an ion exchange reaction between the anion and the functional group of the strong base resin, a quarternary amine. This reaction may be represented by the following equation, where the symbol ⊢ denotes the inert matrix of the resin, R represents the alkane moiety of the quarternary amine, and X represents any anion bonded to the resin.

$$\vdash NR_3^+X^- + Au(CN)_2^- \rightleftharpoons \vdash NR_3^+ Au(CN)_2^- + X^-$$

There are two methods whereby the aurocyanide complex may be eluted from the resin, either the equation above may be shifted to the left by an anion which loads more strongly than $Au(CN)_2^-$, or the aurocyanide complex can be converted to a nonionic complex. Elution using $Zn(CN)_4^{2-}$ or SCN^- are examples of the former technique, and require an additional regeneration step to reconvert the resin to the active form. Elution using thiourea is an example of the latter, and operates according to the following equation:

$$\vdash NR_3^+Au(CN)_2^- + 2(NH_2)_2CS + 2H_2SO_4 \rightleftharpoons$$

$$\vdash NR_3^+HSO_4^- + Au[(NH_2)_2CS]_2^+ HSO_4^- + 2HCN$$

3.2 Weak Base Resins

The matrix of weak base resins consists of primary, secondary, tertiary and quarternary amines. The ion exchange properties of the first three types are governed by the pH of the feed solution.

$$\vdash NR_2H^+X^- \rightleftharpoons \vdash NR_2 + HX$$

The resin is efficient in extracting anions when charged, and therefore at pH values below the pKa of the resin. For the loading of aurocyanide from cyanide solution, typically pH 10.5, a weak base resin would optimally have an average pKa 10.5, i.e., at least 50% of the functional groups on the resin would be protonated at pH 10.5. This would reduce the consumption of acid required to lower the pH of the feed solution for optimal loading.

An important advantage of weak base resins over strong base resins is that they are readily eluted at pH values higher than their pKa:

$$\vdash NR_2H^+Au(CN)_2^- + {}^-OH \rightleftharpoons \vdash NR_2 + Au(CN)_2^- + H_2O$$

In this respect it would be advantageous to use weak base resins which have a minimal number of quaternary amine sites, since anions adsorbed onto these sites would not be eluted by hydroxide during the elution cycle. This would lead eventually to lower extraction efficiency.

Another advantage which weak base resins exhibit over strong base resins, is a selectivity for gold and silver over base metals at high pH values. Although the overall loading capacity of weak base resins is reduced at high pH, the distribution coefficients for multivalent base metals is affected to a greater degree than the distribution coefficients of the monovalent anions $Au(CN)_2^-$ and $Ag(CN)_2^-$.

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This selectivity difference may be due to a reduction in the charge (functional group) density of weak base resins at high pH values. The divalent and trivalent base metal cyanides such as $Cu(CN)_4^{3-}$, $Co(CN)_6^{3-}$, $Fe(CN)_6^{3-}$, $Ni(CN)_4^{2-}$ would require two or more positively charged functional groups in close proximity to achieve neutrality.

3.3 Reducing Resins

Reducing resins operate by electron exchange, rather than ion exchange, reducing the metal ion to the neutral state. The reduced metal is entrapped within the polymer matrix of the resin, and may be recovered by roasting. These resins load precious metals (e.g., Au, Ag, Pt, Pd) selectively, and to high capacity (up to 2g Au/g resin). Unfortunately, the reducing resins currently available, Amborane 345 and 355, do not load gold from cyanide solutions.

3.4 Dense Resins

Dense resins (S.G.$\sim$ 1.3) have been produced by Sentrachem Ltd in South Africa, for testing in the uranium industry. These resins would be advantageous for resin-in-pulp work, since they would allow the use of higher percent solids feed slurries. No reference has been made to the use of these resins in the gold industry.

3.5 Resin-in-Pulp

There are three basic design philosophies available for the separation of gold from pregnant cyanide leach solutions or slurries using resins:

a) Nonselective adsorption, followed by selective elution of gold.
b) Nonselective adsorption and nonselective elution, with the recovery of gold from the concentrated solution.
c) Selective adsorption of gold followed by nonselective elution.

Most of the research to date has centred around the first method, with some success. Nonselective adsorption has the advantage of producing a barren solution essentially free of all metal cyanides. Unfortunately, selective elution generally requires multistage elution cycles to separate gold from all base metal cyanides.

The second method has been the subject of more recent research, and has the advantage of a one stage elution process, rather than the mulitstage elution cycles required by the first method. Also, once the gold has been recovered from the eluate by electrolysis, for example, the spent electrolyte would contain all of the base metal cyanides.

The third method has received limited attention due to the unavailability of commercial resins which extract gold selectively from cyanide leach solutions.

4.0 LITERATURE SURVEY AND REFERENCE LIST

The use of ion exchange resins for the recovery of gold from aqueous solution has been known to be technically viable since 1945 (Sussman et al, 1945). Shortly thereafter, weak base resins (Hussey, 1949), and strong base resins (Burstall et al, 1953) were shown to extract gold from cyanide solution. From these initial studies the major problems were readily apparent: weak base resins have a low loading capacity for aurocyanide (2 to 4 times lower than strong base resins), whereas strong base resins are less selective, loading many base metals species more efficiently than the monovalent aurocyanide complex. Since then, research has remained active, but limited, centering mainly on strong base resins and selective elution techniques for separating gold from the base metals. In the following section, the highlights of the literature to date are outlined chronologically and any apparent shortcomings of the processes involved are discussed with respect to the current research proposal.

1. Sussman et al (1945)

   This first study on the use of anion exchange resins for the recovery of gold demonstrated its potential to extract gold from a chloride solution. An early patent was issued from this group (Nachod, 1945).

2. Hussey et al (1949)

   Hussey investigated the use of a polyamine weak base anion exchange resin, Amberlite IR-4B, to remove gold and silver cyanide from cyanide solutions. Using a countercurrent adsorption and regeneration process, recovery of 95% Au and 79% Ag was reported.

However, the process failed due to the inefficiency of the weak base resin in extracting anions at the high pH levels of cyanide leach solutions. A very high resin to pulp ratio had to be employed to achieve the high gold recovery.

3. Burstall et al (1953)

A strong base resin (Amberlite IFA-400) was found to adsorb gold efficiently from cyanide solutions (up to 0.66 g Au/g resin). Other heavy metal cyanides were also adsorbed (Ag, Cu, Co, Fe, Ni, and Zn) leaving a barren solution. The monovalent aurocyanide complex, $Au(CN)_2^-$, was displaced by multivalent cyanide complexes such as $Cu(CN)_4^{3-}$, $Co(CN)_6^{3-}$ and $Fe(CN)_6^{4-}$. The effect of small ions, likely to be present in commercial cyanide solutions, was investigated. Sulphate ions were found to have no effect, but thiosulphate and thiocyanate were found to reduce the affinity of the resin for gold.

Selective elution of the adsorbed gold was found to be difficult and inefficient using a variety of aqueous eluting agents. The following eluants were tested: 2N NaCl; 5N NH_4Cl; 2N, 4N, 5N and 11N HCl; 1N H_2SO_4; 4N NaOH; 4N NH_4OH; 1N $NaCO_3$; and 1N NaCN. Potassium thiocyanate (2N) was the only aqueous eluting agent found to be effective for gold recovery. Unfortunately, cobalticyanide and argentocyanide were also stripped.

However, elution with various organic solvents was found to be rapid and efficient. A variety of mixtures were tested, and a procedure was developed whereby metal cyanide complexes other than aurocyanide were removed using 0.2N HCl (for Ni and Zn), followed by 1N NaCN (for Cu and Fe). The gold and silver were removed using an acetone-5% HCl-5% H_2O mixture. Any cobalt present could be stripped periodically using 2N KSCN.

Multicyclic operations (100 to 200 cycles) consisting of adsorption, followed by elution with 0.2N HCl and 1N NaCN were recommended to buildup the concentration of gold and silver on the resin. This would be followed by less frequent stripping with the organic, allowing the volume of organic solvent to be minimized, and improving the grade of the gold concentrate produced. This method was reported to recover 99.5% Au and 100% Ag after 3 aqueous cycles followed by one organic strip, plus 2 aqueous cycles followed by one organic strip. The major contaminant recovered with the precious metals was copper (49.7% Au, 41.6% Cu, 5% Ag, 1.7% Zn, 1.3% Ni and 0.7% Fe). The grade of the concentrate could be improved with more cycles prior to organic stripping.

The above studies were carried out on synthetic leach solutions. When the test was repeated on a liquor prepared by cyanidation of a low grade ore, the first stage of elution with 0.2N HCl was found to convert metal species on the resin to complex species that were difficult to desorb.

An unattractive feature of this process is its complexity, since a four stage elution operation is required if Ni, Zn and Co are present as contaminants. If Ni and Zn are not present in high concentration in the pregnant liquor, the first step, and its associated problems may be eliminated.

Other resins tested in this study were Amberlite IR-45, Deacidite E, Resanex and Amberlite XE-75. The first three, which are weak base resins, were found to have a low capacity for gold. Amberlite XE-75 had similar capacity to Amberlite IRA-400, but lacked the selective elution properties exhibited by IRA-400.

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4. Davidson et al (1961)

Davidson et al (1961) continued the study of strong base resins for gold recovery, and compared it favourably to conventional zinc precipitation provided that the pregnant solution was high in gold and relatively free of competing metal cyanide complexes. Their design philosophy was for the selective adsorption of gold, followed by nonselective elution. Pure gold was recovered from the eluate by electrolysis. The most efficient recovery of gold was obtained when the elution and electrolysis were carried out in a continuous and closed electroelution cycle.

5. Slater (1974)

This paper deals primarily with the physical and design aspects of the treatment of pulp with resin in ion exchange columns. If a countercurrent process is desired, the author expresses the view that the resin must be capable of sinking in the pulp, and refers to various commercially unsuccessful attempts to operate with dense pulps sinking in resin which will float. The important parameters are the pulp solids concentration and the resin density. A practical lower limit of 10 to 20% solids is provided for reasonable bed expansion and flow rates assuming a standard resin of 50 mesh. Cycloning or thickening the pulp is suggested to eliminate coarse solids ($>$ 150 mesh) which would not pass upwards, but would be removed from the column with the resin, if present.

Advantages of columns over horizontal arrangements of agitated vessels are cited to be: attrition of the resin by agitation is eliminated; interstage screening to separate pulp and resin is avoided; and the difficulties of interstage resin transfers are minimized.

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This process would have more promise in the present investigation if higher density resins (S.G. ~ 1.35) were available, allowing higher percent solids in the pulp.

6. Zokharov et al (1975)

This paper investigates the use of pulsating adsorption columns for the extraction of gold from nonclarified solutions, and included a pilot plant test. This process is considered to be inappropriate to the present investigation due to the low levels of suspended solids (0.02 to 0.05% solids), and the low recovery rate (83% Au)

7. Duzhina et al (1976)

This paper discusses the adsorption of gold and silver onto a redox resin from cyanide waste effluent. The major advantage cited, with respect to ion exchange resins, is that redox resins are more efficient at stripping waste cyanide solutions. Thus, outflowing solutions contained 0.0003 to 0.001 mg Au/L, compared to 0.002 to 0.0044 mg Au/L after treatment of a 0.01 mg/L gold solution through a redox resin and an ion exchange resin, respectively. Also, the electron exchange resin was found to be kinetically superior to the ion exchange resin.

Redox resins are described to be chemically stable and of greater mechanical stability when compared to ion exchange resins. With respect to the processing of pulp, the use of very large mesh (500 μm) redox resin was not found to affect the redox sorption of gold. Gold and silver are eluted readily from the saturated redox resins using thiourea. The regenerated resin may be reused efficiently.

Unfortunately, the resin employed in this work (called 'Redox Resin 1') is described only as a sulphur bearing electron exchange resin with an oxidation potential of 0.6V. Originating in the USSR, its availability is doubtful.

8. Anon. (1978)

Many references have been made in the literature to progress in the development of resin in pulp for gold extraction in the Soviet Union. This 1978 report states that one of the largest gold mines in the Soviet Union (the Muruntau open pit mine) is using an anion exchange resin to extract aurocyanide by an RIP process. This is believed to have been the first commercial application of RIP ion exchange techniques to recover gold from cyanide pulp, although the author states that RIP is used widely for gold extraction in the USSR.

In their process, nonselective adsorption is followed by selective elution. Mineral acid is employed to elute Ni and Zn. An ammoniacal solution of ammonium nitrate elutes the Cu and, finally, gold and silver are desorbed and electrowon in a continuous process, using acidified thiourea.

As with the process advanced by Burstall et al (1953), the three stage elution operation is expensive, and the use of acid in the first elution stage can cause the formation of hard to elute metal complexes.

9. Stamboliadis et al (1978)

This work repeated some of the studies by Burstall et al (1953) on the removal of aurocyanide from Amberlite IRA-400, and on finding similar results as the initial paper published 25 years earlier, did an economic comparison of the use of ion exchange resins versus zinc precipitation for the recovery of gold from cyanide solutions.

The eluting agents tested were 2N NH_4SCN, which was found to be effective at removing Au, Ag, Zn, Ni and Cu (Fe remained on the resin), and the process of 0.2N HCl (to remove Ni and Zn) followed by 2N NaCN (to remove Cu and Fe) and acetone-5% HCl -5% H_2O (to remove Au), first advanced by Burstall et al (1953).

The cost comparison showed thiocyanate elution to be 22 times more expensive than zinc precipitation, while the HCl/NaCN/Acetone-HCl process was 65 times more expensive than zinc precipitation. Also, it was noted that the cost of removing the impurities, such as Cu using NaCN, was four times greater than the cost of recovering the gold. A second drawback discussed was that the resin is not used efficiently for the recovery of gold. Base metals such as copper, nickel and iron cyanides generally are present in higher concentration in the pregnant feed solution, and can occupy as much as 95% of the resin capacity.

One short coming of this work is that it makes no attempt to identify, nor to evaluate economically any methods around these economic disadvantages. First of all, their study was carried out on clarified solutions, and involved one cycle of adsorption, aqueous stripping of base metals, and organic stripping of gold and silver.The economic advantages to be gained by bypassing the filtration step and using an RIP application were not taken into account. Also, the use of repetitive cycles of adsorption followed by base metal stripping with aqueous reagents was not considered. This latter adaptation would substantially reduce the cost of the organic stripping step, as it would be carried less frequently, perhaps after 100 or 200 cycles of adsorption/base metal stripping, as first suggested by Burstall et al (1953).

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10. Hazen (US Pat. 2 810 638)

Hazen proposed the use of a saturated solution of sodium zinc cyanide to elute gold from a strong base resin. The aurocyanide solution is then passed through a bed of zinc powder, where the gold cements onto the zinc, and the zinc cyanide that is generated is recycled to elution.

The work was abandoned because it was believed that the concentration of zinc in a saturated solution was only 4 g Zn /L, resulting in the economically unfavourable use of vast volumns of eluent to remove the gold. This line of research was reinvestigated by Fleming and Cromberge (1984 b; see below), after it was determined that a sodium zinc cyanide solution can contain 0.5M Zn or 33 g Zn/L.

11. Fleming and Cromberge (1984 a)

This paper is the first in a series of three papers (see below), and together they represent the most recent and detailed study to date on the extraction and elution of aurocyanide by strong and weak base resins, as well as a report of a small scale pilot plant test on the resin in pulp extraction of gold from cyanide media.

These workers rejected the complex multielution procedures of Burstall et al (1953), and proposed nonselective adsorption and nonselective elution stages (employed essentially to concentrate all metal species in solution) followed by the selective recovery of gold and silver by electroysis. The spent electrolyte would contain all of the base metals cyanides.

In the first paper, the effect on gold adsorption of parameters such as gold concentration in pregnant feed solutions, pH, temperature, agitation, ionic strength, and the presence of competing ions were investigated using both strong (Amberlite IPA-400) and weak (A7 or MG1) base resins. The results reported are summarized in the table below.

	STRONG BASE RESIN		WEAK BASE RESIN	
Parameter	Rate of Au Loading	Equil. Capacity	Rate of Au Loading	Equil. Capacity
Concentration of Gold	First order in Au concentration	Increases with increasing [Au], up to ~220 g/l (in absence of competing ions)	N.A.	N.A.
pH (0-12)	no effect	no effect	independent if pH < 8; decreases if pH > 8	maximum capacity at pH 4 to 8
Ionic Strength (0 to 0.05 M)	no effect	Decreasing capacity with increasing ionic strength	no effect	Decreasing capacity with increasing ionic strength
Temperature (30 to 80°C)	Increases with increasing temperature	Decreases with increasing temperature	Increases with increasing temperature	Decreases with increasing temperature
Agitation	increases with improved mixing	N.A.	Increases with improved mixing at loading < 4g/L	N.A.

The authors found that copper, nickel and zinc cyanides are more strongly adsorbed than gold, whereas cobalt, silver and iron cyanides are less strongly adsorbed than gold on both the strong and weak base resins tested. From the relative stability of these complexes, (Co^{3+}, log $\beta 6 \sim 64$; Au^{+}, log $\beta 2 = 47$; Fe^{3+}, log $\beta 6 = 44$; Fe^{2+}, log $\beta 6 = 35$; Ni^{2+}, log $\beta 4 = 30$; Cu^{+}, log $\beta 4 = 28$; Zn^{2+}, log $\beta 4 = 19$) the authors suggested the selective precipitation of the base metal cyanides at pH values between 6 and 3. The cyanide complexes of Zn, Cu and Ni break down, producing insoluble cyanide species. Indeed, gold loading was found to improve significantly at pH 7, due to the decrease in competition from the base metals which had precipitated.

Two foreseeable problems with this suggestion is the expected formation of large quantites of crystalline calcium sulphate in this pH range, and an additional liquid-solid separation step.

For weak base resins, increased selectively for gold and silver over base metal cyanide complexes was observed at high pH values. This effect was not observed when using strong base resins.

12. Fleming and Cromberge (1984 b)

In the second paper in this series, various methods of eluting gold from both strong base and weak base ion exchange resins were examined, as were the effects on the rate of elution of gold of factors such as eluent concentration, temperature, and the concentration of gold in solution.

In all cases, the method of elution studied incorporated the electrolytic recovery of gold within the elution cycle. This method was chosen since rapid flowrates of eluent through the

reactor, producing vast volumes of very dilute gold eluate, would still allow for maximized overall rate of recovery, provided that the rate at which gold is deposited in the electrowinning cell exceeds the rate at which it is eluted from the resin.

Their results are summarized in the following tables, for the elution of strong base resins using zinc cyanide, ammonium thiocyanate, and thiourea, and the elution of weak base resins using sodium hydroxide.

ELUENT	STRONG BASE RESIN			
	$Na_2ZN(CN)_4$		NH_4 SCN	
Parameter	Rate of Elution	Electrowinning Efficiency	Rate of Elution	Electrowinning
Concentration of eluent	no effect if>10 g/L (T=50°C)	no effect if>10 g/L (T=50°C)	linear increase with increasing concentration	n/a
Temperature	increases with increasing temperature	increases with increasing temperature	increases with increasing temperature	increases with increasing temperature
Cell Current	increases with increasing cell current	increases with increasing cell current	increases with increasing cell current	increases with increasing cell current
Eluent flowrate	increases with increasing flowrate	increases with increasing flowrate	increases with increasing flowrate	increases with increasing flowrate

	STRONG BASE RESIN		WEAK BASE RESIN	
ELUENT	$CS(NH_2)_2$ in H_2SO_4		NaOH	
Parameter	Rate of Elution	Electrowinning Efficiency	Rate of Elution	Electrowinning Efficiency
Concentration of eluent	linear increase with increase in $[CS(NH_2O_2]$ and $[H_2SO_4]$	increases with increasing $[CS(NH_2)_2]$: no effect with $[H_2SO_4]$	increases with increasing concentration up to 0.5 M	increases with increasing concentration
Temperature	increases with increasing temperature	increases with increasing temperature	increases with increasing temperature	increases with increasing temperature
Cell Current	no effect	increases with increasing cell current	no effect	No effect
Eluent flowrate	no effect	increases with increasing flowrate	no effect	N.A.

For all four reagents, the rate of gold deposition on the cathode exceeded the rate of gold elution, as required by a successful electroelution process.

Thiourea was the least attractive eluent for strong base resins, since it decomposes in acidic solutions producing elemental sulphur. The potential for efficient recycling of $Zn(CN)_2^{2-}$ or SCN^- has favourable economic advantages, reducing the operating cost to a level comparable to zinc cementation. Elution and electrowinning of gold using thiocyanate was the best reagent tested for strong base resins.

Concerning the stripping of other metal cyanides during the elution cycle, $Zn(CN)_4^{2-}$ was by far the best at stripping Ag, Co, Cu, Ni, Zn, Fe, and no elements accumulated on the resin during cyclic operation.

Their results showed that the weak base resins are superior to the strong base resins, in terms of the rate of elution. The weak base resin would require the shortest elution cycle (1 to 2h), whereas the strong base resins would require 6 to 10 h for elution with SCN^-, and 6h for elution with $Zn(CN)_2^{2-}$ or $CS(NH_2)_2$ at 50 to 60°C.

Although the weak base resin is superior on many accounts, the capacity of weak base resins is 2 to 4 times lower than that of strong base resins at the pH values typical of cyanide leach solutions. This would result in higher resin inventories, and more extraction stages in the absorption cycle.

13. Fleming and Cromberge (1984 c)

In the final paper in this series, the results of a number of small scale RIP pilot plant campaigns at mines in South Africa are reported, and are compared to the normal CIP process under identical conditions and feed material.

The authors found that both strong and weak base resins extracted gold cyanide efficiently from pulp, under the same operating conditions as those used in CIP processes. Resins were more efficient than activated carbon when the concentration of competing anionic complexes was low, but were less efficient when the concentration of competing anions was high.

The gold extraction efficiency of resins was significantly better than that of activated carbon for the treatment of calcine. This was attributed to the adsorption of calcine on the surface of activated carbon, but not on the surface of resin.

Elution with 0.5M zinc cyanide solution for strong base resins, or 0.5M sodium hydroxide solution for weak base resins, reduced the concentration of gold on the resin to less than 100 g/t, reducing the losses of soluble gold to less than 0.01 mg/L when the eluted resin is recycled to the adsorption stage. This was accomplished in a 24h elution cycle.

They reported that for strong base resins, the zinc cyanide elution method was substantially cheaper than either the thiourea or the thiocyanate method. However, this did not take into account the potential for recycling the eluted thiocyanate.

14. Green and Potgeiter (1984)

This recent work carried out at MINTEK, reports on the results of attempts to produce high pKa weak base resins. Elution of strong base resins is possible only by ion exchange, or by conversion of the ion on the resin to a nonionic species. Weak base resins may be stripped by deprotonation of the functional group of the resin, in addition to the above two methods. This versatility is an advantage. Unfortunately, most commercially available weak base resins consist of alkylamines, and are most efficiently loaded at pH values below 8, and stripped at pH values above 10. Since typical gold leach liquors are at pH 10.5, the pH of the solution must be lowered prior to loading the resin. A resin prepared from a higher pKa functional group would be expected to exhibit a higher pH value for optimal gold loading, eliminating the need for pH adjustment.

To this end, the authors synthesized and investigated various resins containing imidazole and tetrahydropyrimidine groups which exhibited pKa values of the order of 9.7 to 10.2. The authors did find a correlation between the pH of maximum aurocyanide extraction and the pKa of the resins tested, although the physical nature of the resin matrix also had an effect on gold loading performance. One resin with an apparent pKa of 10.2 exhibited maximum gold extraction at pH 9.8. This characteristic, coupled with the possibility of elution using sodium hydroxide, make these high pKa weak base resins very attractive for use in the extraction of gold from cyanide leach liquors. The only drawback observed by the authors was a slow degradation of the resin, resulting in lower capacities. The cause of the degradation was undetermined.

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15. Mehmet and Te Riele (1984)

Commercial plants in South Africa currently employ activated carbon in NIMCIX contractors or in fixed bed columns to successfully recover gold from cyanide leach streams. This paper reports the results of pilot plant test work conducted at MINTEK using both strong base and weak base ion exchange resins in a NIMCIX countercurrent contractor to recover gold from such streams. The two resins tested were Duolite A7, a weak base resin and Amberlite IRA-400, a strong base resin.

For the strong base resin, five stages were required to attain the desired barren solution concentration of 0.005g of Au per ton of solution, resulting in adsorption of 99.9% of the gold. Gold loadings on the resin reached 4860 g/t with as little as 29g of Au per ton of resin remaining on the eluted (using zinc cyanide) and regenerated (using sulphuric acid) resin. The gold was electrowon continuously from the eluate, reducing the consumption of eluant, which was recirculated to the elution column.

Only 0.45% of the resin capacity was utilized in recoverying the gold; 35.4% was used to recover the base metal cyanides. All of the base metals were eluted satisfactorily from the resin with the exception of nickel and lead. At the end of the campaign, there was no accumulation of any species on the resin during cyclic operation; there was no loss in the equilibrum capacity of the used resin for gold, and there was no microscopic evidence of physical degradation of the resin.

When using the weak base resin, the pH of the feed solution was reduced from 11 to 6.7 prior to adsorption.

Seven stages were employed and the gold in the barren solution was 0.002 g/t, for 99.9% gold adsorption. The loaded resin contained 1650 g/t of gold. Base metals (Co, Cu, Fe, Ni) were removed to acceptable levels in the barren solutions. Only 0.1% of the nominal resin capacity was used for gold loading, and only 6.8% was utilized by other cyanide species. The eluant (sodium hydroxide, pH = 13.2) removed the gold from the resin to acceptable levels (7.9 g/t in 2 days) but not silver, zinc, lead, nickel nor iron. Zinc and nickel were removed efficiently during resin regeneration using sulphuric acid. At the end of the pilot plant campaign, no species had accumulated on the resin, there was no loss in equilibrium capacity nor kinetic performance during cyclic operation, and there was no physical degradation apparent under microscopic examination.

The authors concluded that both strong and weak base resins could be employed successfully to recover gold from clarified cyanide leach liquor in a NIMCIX column. Solutions with gold concentrations up to 2 g/t will yield a barren solution containing 0.002 g/t. Both types of resin may be eluted and regenerated satisfactorily. A cost comparison for reagents showed the weak base resin was significantly cheaper. The elution of weak base resin is also less labour intensive and requires only sodium hydroxide. The authors suggested that if the pKa values of weak base resins could be increased, allowing for an increased loading capacity, and eliminating the pH adjustment step, these resins would be far superior to strong base resins.

16. Law et al (1985)

The influence of various organic/aqueous mixtures, and the effect of temperature, on the elution of gold cyanide from Amberlite IPA-400 and IPA-900 during equilibrium studies was reported.

Organic/aqueous mixtures were found to be better eluants than aqueous solutions. Using mixtures of 50% DMF with 2.44 M NH_4SCN, 2.44M KSCN or 4M NaOH, the two thiocyanate mixtures were found to be far superior to the sodium hydroxide. Thiourea (3.25 M) in KOH (2M) and 75% DMF performed better than the NaOH mixture, but not as well as either NH_4SCN or KSCN in 50% DMF. Optimization of the elution cycle using KSCN resulted in 55% gold desorbed from the resin using 5M KSCN.

Organic solvents tested were HMPA (hexamethyl - phosphoramide), THF, acetone, DMF, DMA, DMSO, and MP (N-methyl-2-pyrrolidinone). Acetone, DMA and DMF all performed well, desorbing 50% of the gold.

The authors recommended 5M KSCN in 50% DMF for gold recovery from anion exchange resins.

The rate of elution was found to be faster at 45°C, although the elution equilibrium was not affected by temperature.

In summary, all authors agree that strong base resins are more effective than weak base resins for the separation of gold from cyanide solutions. Although strong base resins are more difficult to strip, they load aurocyanide more efficiently. Reduction of the pH of the slurry for use with weak base resins having lower pKa's has resulted in massive calcium sulphate formation. Although weak base resins do show some selectivity for gold over base metal cyanides at high pH, their maximum loading capacities are far lower than those of strong base resins, and decrease with increasing pH. There have been suggestions in the literature, aimed at resin manufacturers, concerning the production of high pKa weak base resins. A significant advantage to weak base resins is the ease of stripping gold using aqueous reagents, rather than the organic solvents required with strong base resins.

One classification of resin which has received limited attention in the gold recovery literature is macroporous resins. The physical strength of conventional gel type resins is related to the degree of crosslinking within the bead. Unfortunately, as the crosslinking is increased to produce a stronger bead, the rate of diffusion of solution through the bead decreases. Macroporous resins are high porosity resins with a high degree of physical strength. These would be advantageous to resin in pulp work for two reasons. Firstly, an increase in physical stability would reduce attrition during agitation and secondly, larger beads could be produced which would simplify the screening separation of resin from the slurry.

High density resins (S.G. $\sim$ 1.35) have been produced for testing in the uranium industry. There is no indication of any work being carried out with these resins for the recovery of gold.

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In summary, the areas of research which show the most promise for process improvement are the investigation of high density and/or large mesh size macroporous resins; either strong base or high pKa weak base resins.

The nonselective adsorption, nonselective elution process with the electroytic recovery of gold in a closed electroelution cycle also warrants further investigation.

Finally, the use of a reducing agent, such as SO_2, to reduce the gold on the resin to the metallic state, with the simultaneous elution of the nonreduced metals (i.e., Cu, Fe, Zn etc.) should be investigated. In this case, the stripped resin containing only metallic gold, could be reloaded many times in a multicyclic loading, gold reduction, base metals stripping process, before finally recovering the gold.

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5.0 PROCUREMENT AND PREPARATION OF ORE, PULP AND RESIN SAMPLES

5.1 Procurement and Preparation of Ore and Pulp Samples

Both ore and pregnant cyanidation leach pulp was received from a mine in the Hemlo area (Teck-Corona). Two separate samples of ore, which had been previously ground and screened to 100% minus 200 mesh, were subjected to a cyanidation leach. This began with an 8 hours preaeration stage, during which time the pH of the pulp was maintained above pH 10 using lime. Preaeration was followed by a 48 hour cyanidation leach during which the pH was maintained above 10.5 and the available cyanide concentration was maintained at 0.5 g/L CN. The resulting slurries were filtered and the pregnant gold solution was used for the first part of test program (Tests 1 to 8) where resin was contacted with solution only.

The first shipment of pregnant cyanidation leach slurry was used for the laboratory tests 9 to 13, where resin was contacted with pulp. The as-received slurry was prescreened to 100% minus 200 mesh to remove tramp material and to allow for facile resin/pulp separation. The pulp was diluted to 18% solids, the pH was maintained at pH 10.6 and the available cyanide level was maintained at 0.3 gpl CN.

The second shipment of pregnant cyanidation leach slurry was used for the remaining laboratory test 14 as well as the mini-plant run. In order to ensure complete solubilization of the gold, a brief cyanidation leach was carried out where the pH was maintained greater than 10.5, and the available cyanide level was maintained above 0.2 gpl CN. For test 14, the pulp was prescreened to 100% minus 200 mesh and adjusted to 45% solids. For the mini-plant run, the pulp was 100% minus 100 mesh and adjusted to 41% solids.

5.2 Procurement and Preparation of Resin

Three commercially available resins and four experimental resins were considered for the test program. The three commercially available resins were the Rohm and Haas resins Amberlite IRA-400 and Amborane 345 and the Bayer resin Lewatit MP-500.

Meetings were held with the resin manufacturers prior to initiation of the test program. This resulted in three experimental resins being provided to Witteck for inclusion in the current test program (Dow resins XU-40114.00 and XU-40139.00 and Bayer resin OC-1014).

Finally, a fourth experimental resin was obtained by contacting a manufacturer in South Africa concerning specialty high density resins. The resin, Duolite ES-137 C, was obtained directly from the manufacturer in South Africa.

A brief description of the seven resins considered for the program follows:

1.	Amborane 345	:	reducing resin
2.	Amberlite IRA-400	:	strong base gel-type
3.	Lewatit MP-500	:	strong base macroporous
4.	XU-40114.00	:	weak base macroporous, high pKa
5.	XU-40139.00	:	weak base macroporous, high pKa
6.	OC-1014	:	thiourea macroporous
7.	Duolite ES-137 C	:	strong base gel-type

Although it was hoped that a reducing resin would be included in the test programs, literature received with the reducing resin, Amborane 345, indicated that aurocyanide does not show any reactivity toward the reducing resin. Consequently this resin was not included in the test program.

All resins were converted to the hydroxide form prior to loading testwork. This was carried out by contacting the resin batchwise with 2M NaOH. For tests 9 to 14, where pulp was used, the resins were prescreened to 100% plus 50 mesh.

6.0 METALLURGICAL EVALUATION OF THE RESINS

6.1 Benchscale Loading Testwork

Fourteen benchscale equilibrium adsorption tests were carried out to evaluate the various resins. The methodology and results are provided below. In addition, one benchscale kinetic test was conducted; the results are provided in Section 6.1.3.2.

6.1.1. Methodology

In order to mimic a countercurrent resin-in-pulp process, a series of batch-contact stages were conducted. In the first stage, resin was contacted with pregnant leach solution (tests 1 to 7) or leach pulp (tests 8 to 14). For each litre of feed solution or pulp, 1 mL of resin was added. To ensure that equilibrium was attained, the solution-resin or pulp-resin mixture was agitated in a leach vessel overnight. Then the resin was separated either by decantation (solution tests), or by screening through a 100 mesh screen (pulp tests).

For the second and subsequent stages, the leach solution or pulp from stage 1 was contacted repeatedly with a fresh aliquots of resin, while the resin from stage 1 was contacted repeatedly with a fresh aliquots of pregnant leach solution or pulp. This was continued until the gold concentration in the stage 1 solution or pulp filtrate was less than 0.01 ppm, and the gold concentration in the fresh solution or pulp remained unchanged after 24h contact with the stage 1 resin sample. In this manner, the feed solution or pulp was stripped completely of its gold value, and the resin was fully loaded, producing a complete loading isotherm.

6.1.2 Characterization of Feed Solution or Pulp

The feed solution or pulp filtrate for each equilibrium test was sampled and assayed for Sb, As, Cu, Au, Fe, Ag and Zn. The results are provided in Table 1 below. In all cases, the feed solution or pulp was maintained at pH greater than or equal to 10 by the addition of lime, and at 0.2 gpl CN by the addition of NaCN. When using the weak base resins, XU-40114.00 and XU-40139.00, the pH was maintained at pH 10. All elements present in the feed solution or pulp were followed during the equilibrium testwork.

Table 1

ANALYSES OF FEED SOLUTION AND PULP

Test	Feed (% Solids)	Analyses, ppm Sb	As	Cu	Au	Fe	Ag	Zn
1 and 2	Solution	15	1.3	8.5	1.21	74	0.80	4.3
3	Solution	18	4.3	9.1	1.08	55	0.49	3.7
4 to 7	Solution	2.1	<0.08	2.1	1.74	1.6	0.027	0.62
8	Solution	5.3	<0.08	7.1	1.33	5.5	0.23	2.5
9 to 11	Pulp (18%)	<0.05	0.32	25	1.46	12	0.098	0.54
12	Pulp (18%)	<0.05	0.20	43	1.27	16	0.016	3.8
13	Pulp (18%)	<0.05	<0.08	52	1.40	18	0.038	4.6
14	Pulp (45%)	<0.05	2.7	63	6.44	55	0.003	4.0

6.1.3 Experimental Results of Loading Testwork

6.1.3.1 Equilibrium Studies

For test 1, using the Bayer experimental resin OC-1014, neither gold nor any of the base metals were adsorbed by the resin. After each batch contact, the assay for each element in the pregnant leach solution was within experimental error of the assay for the feed solution.

The experimental data for tests 2 to 14 are provided in Figures 1 to 13. The results are discussed below for each resin tested.

Amberlite IRA-400 (Tests 2 and 4)

As shown in Figures 1 and 3, Amberlite IRA-400 loads As, Cu, Fe, Ag and Zn in addition to Au. Antimony did not load. For test 4, arsenic was below the detection limit and Ag was present at very low concentration in the feed solution (0.027 ppm). Although too low to be shown accurately in Figure 3, Ag did load during test 4 to 0.25 kg Ag/t resin.

Although Cu loaded onto the IRA-400 resin during test 4, it did not load during test 2. This was due to the much higher concentrations of the other base metals in the feed. Iron in particular was present in the feed to test 2 at a level of 74 ppm compared to 1.6 ppm for test 4.

The gold loadings for tests 2 and 4 were 2.1 and 14.5 kg/t (61.2 oz/t and 423 oz/t), respectively. The higher gold loadings for test 4 are also explained by the iron levels. During test 2, iron loaded to a maximum of 32 kg Fe/t resin, compared to 22 kg/t of resin for test 4.

Dow XU-40114.00 (Tests 3, 7, 10, 12 and 14)

This experimental Dow resin was used for five of the batch contact tests. Tests 3 and 7 were performed using pregnant solution; tests 10 and 12 were with pregnant pulp at 18% solids; and test 14 was with pregnant pulp at 45% solids.

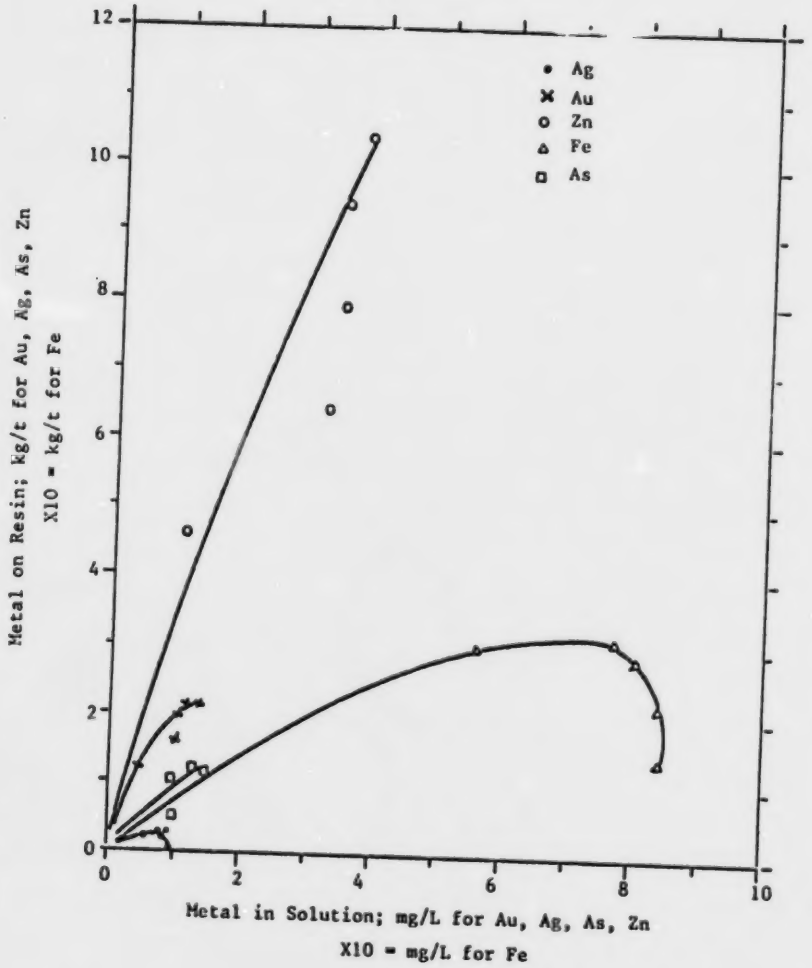

FIGURE 1: TEST 2. AMBERLITE IRA-400

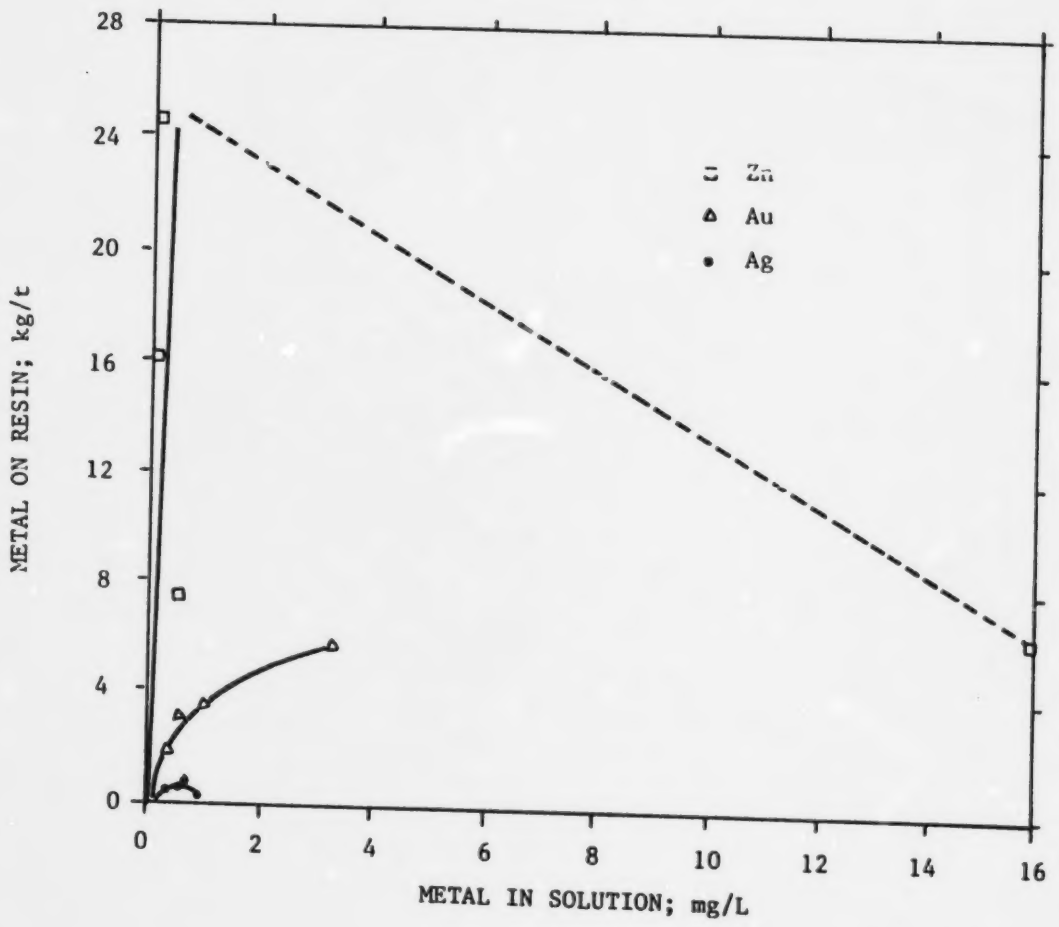

FIGURE 2. TEST 3. DOW XU-40114.00
(see text p 53 for explanation
of zinc loading curve)

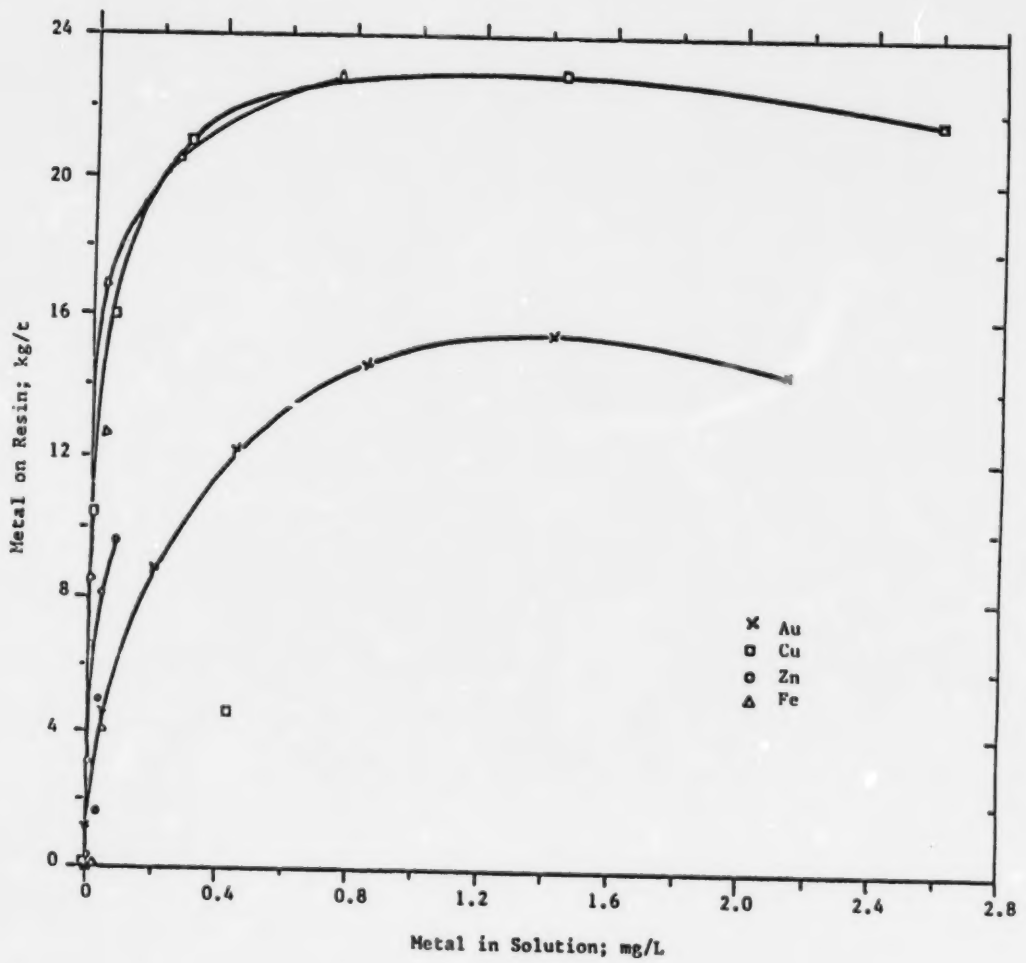

FIGURE 3: TEST 4. AMBERLITE IRA-400

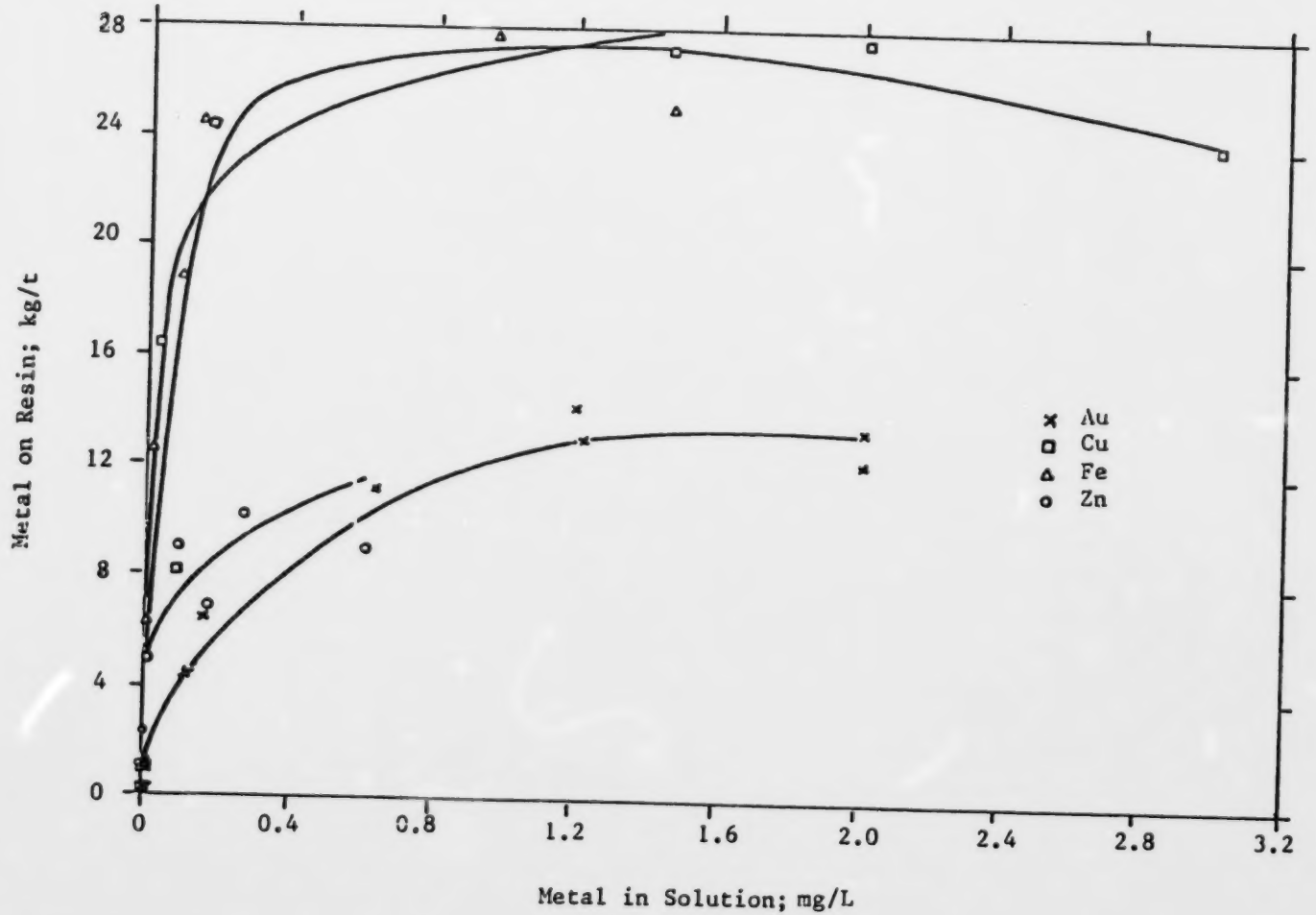

FIGURE 4: TEST 5. LEWATIT MP-500

WD1

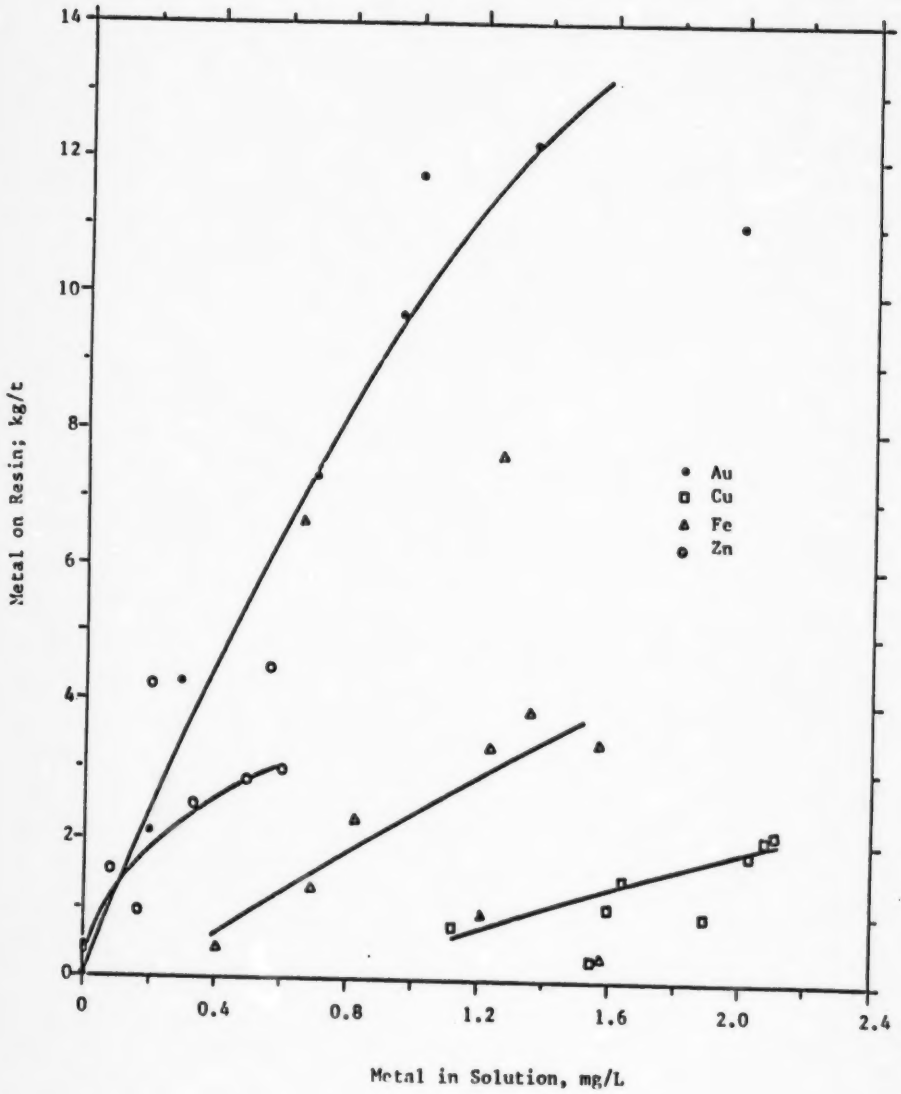

FIGURE 5: TEST 6. DOW XU-40139.00

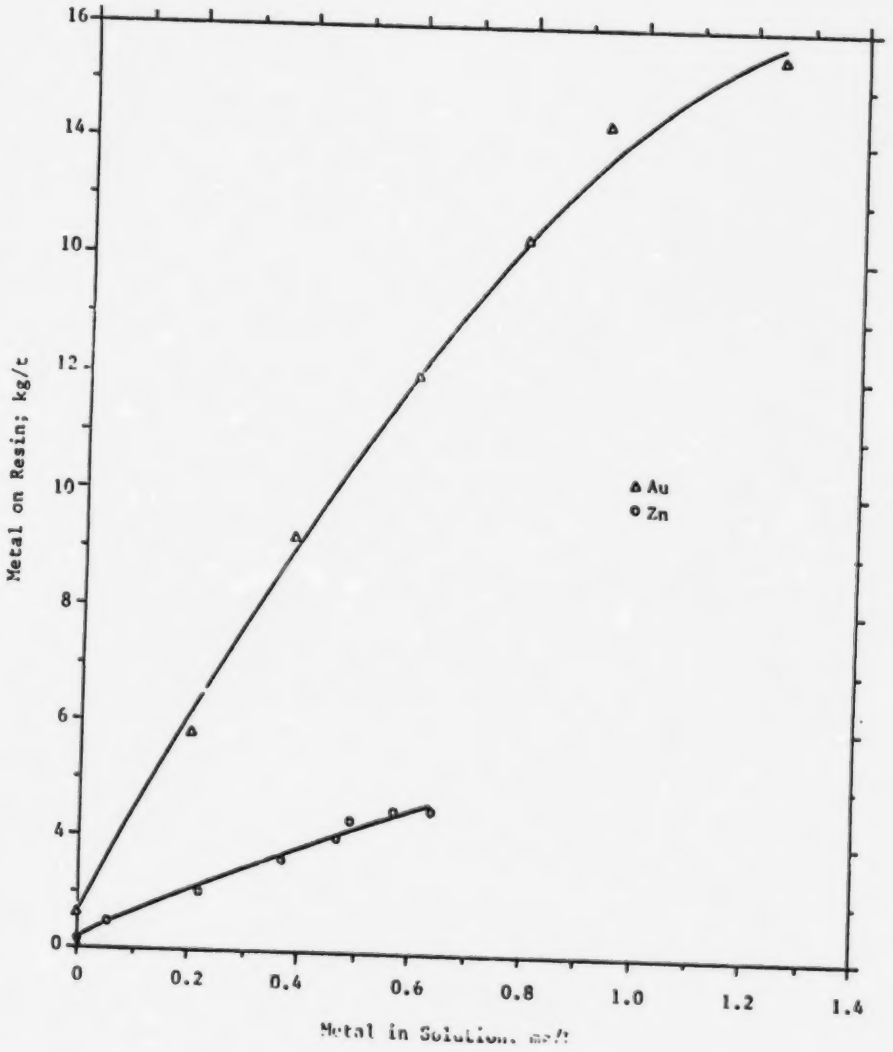

FIGURE 6. TEST 7. DOW XU-40114.00

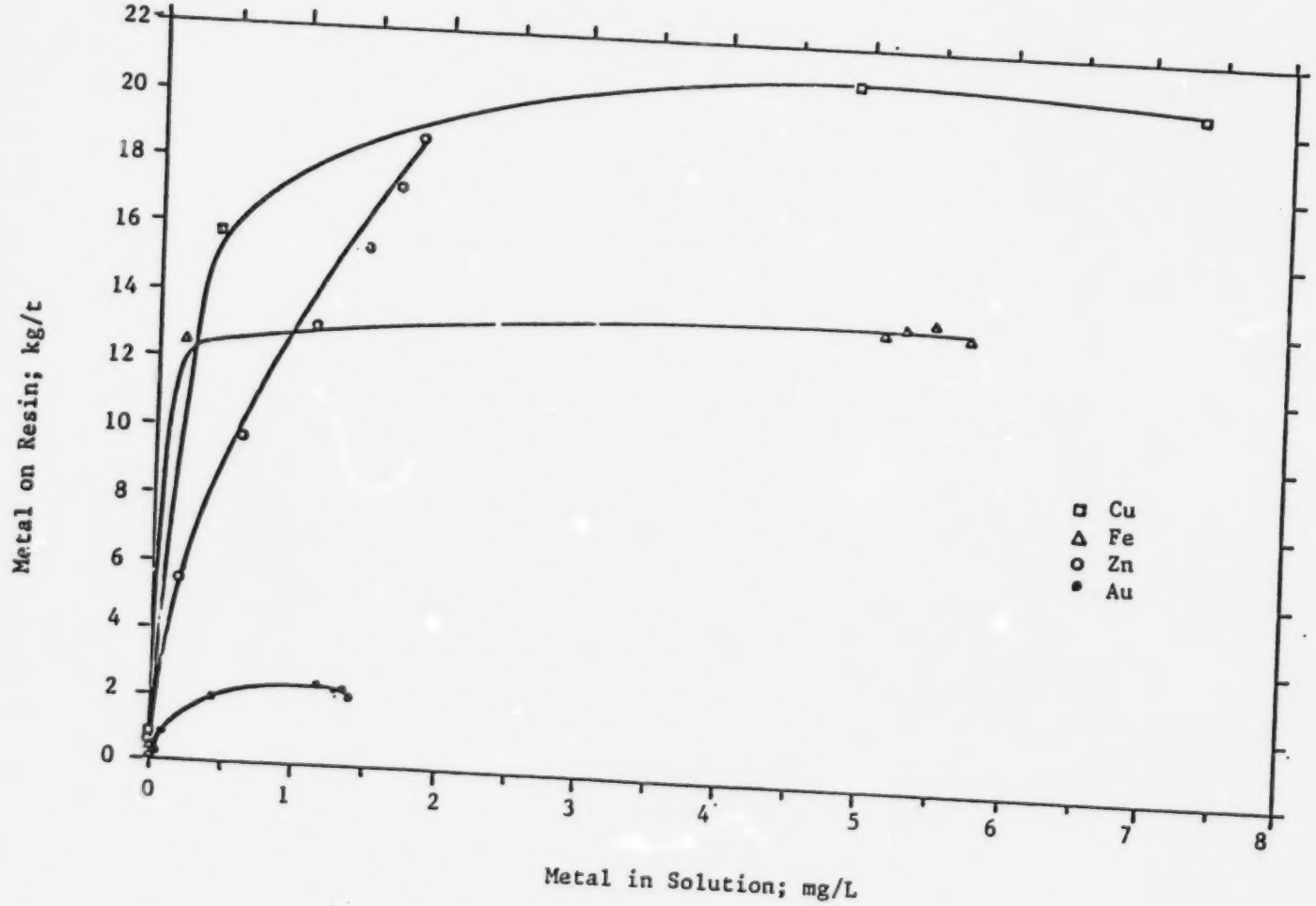

FIGURE 7: TEST 8. DUOLITE ES-137C

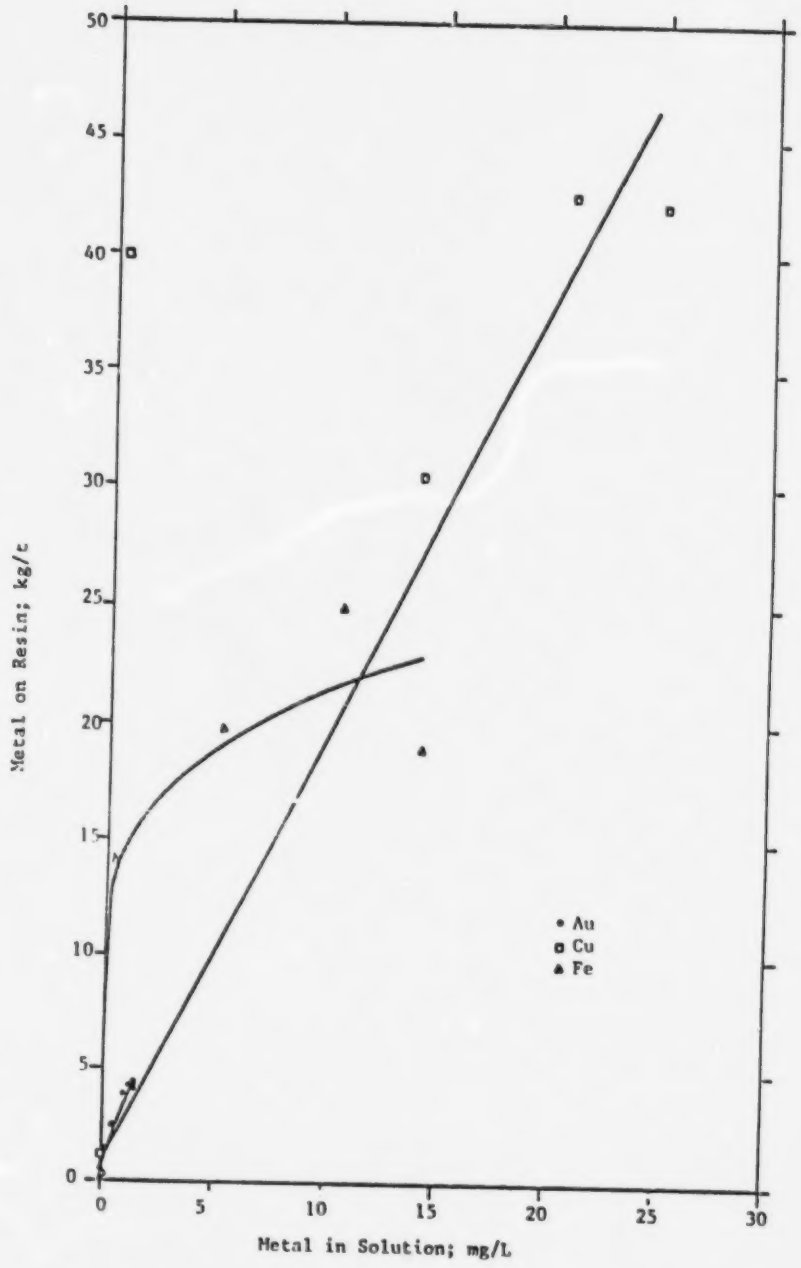

FIGURE 8: TEST 9. LEWATIT MP-500

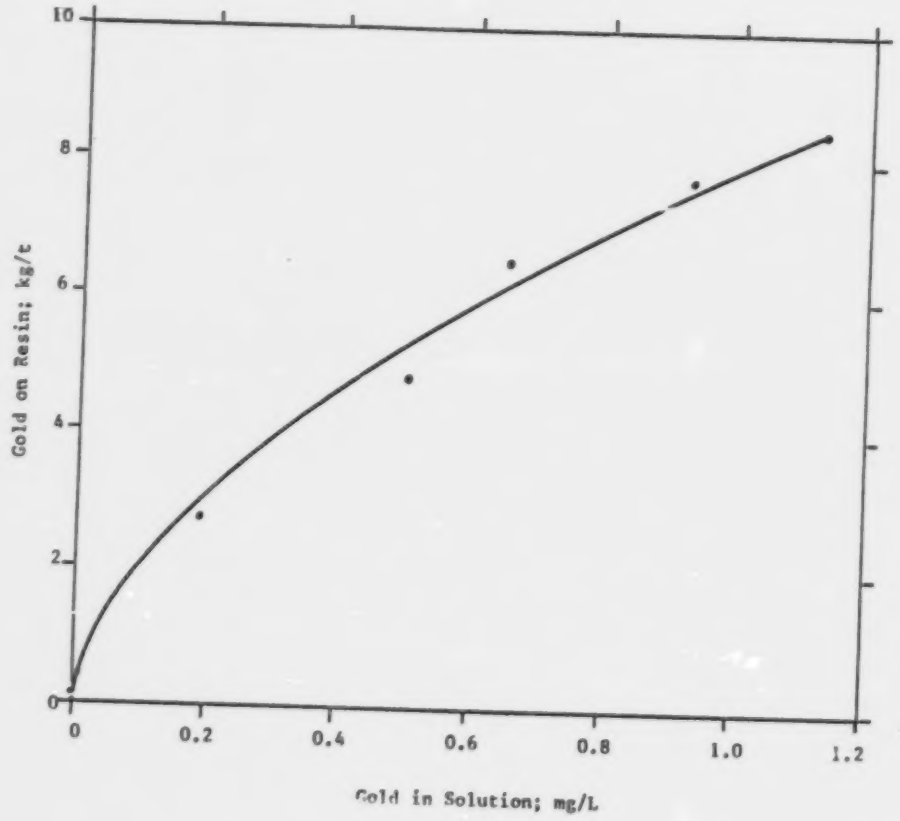

FIGURE 9: TEST 10. DOW XU-40114.00

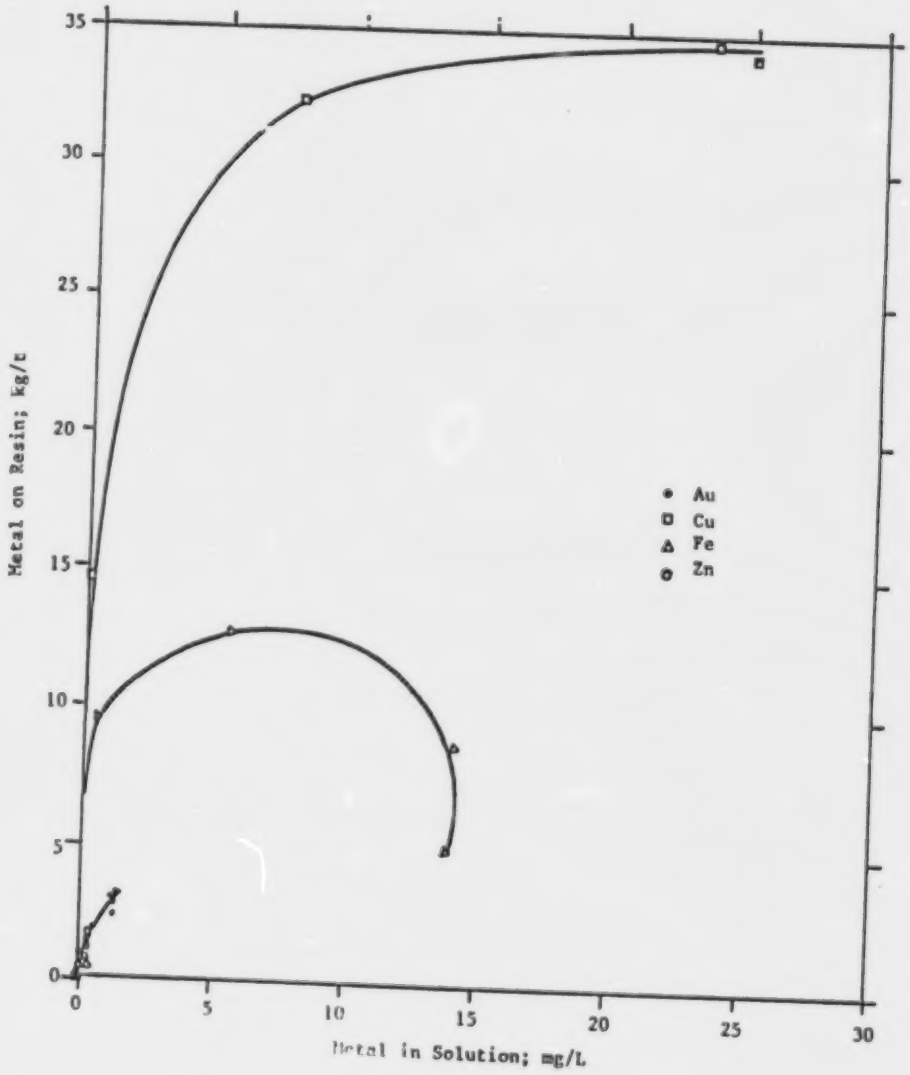

FIGURE 10: TEST 11. DUOLITE ES-137C

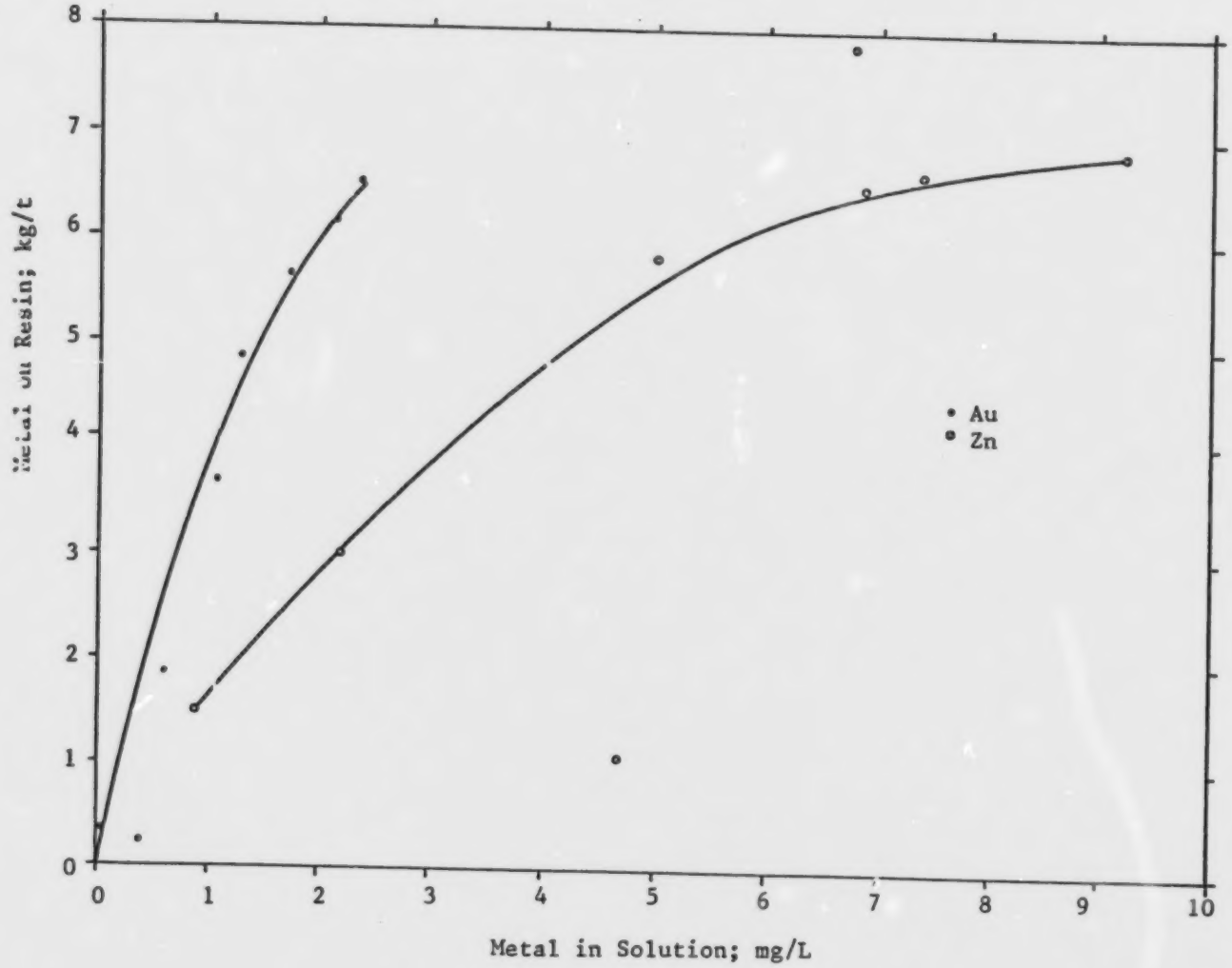

FIGURE 11: TEST 12. DOW XU-40114.00

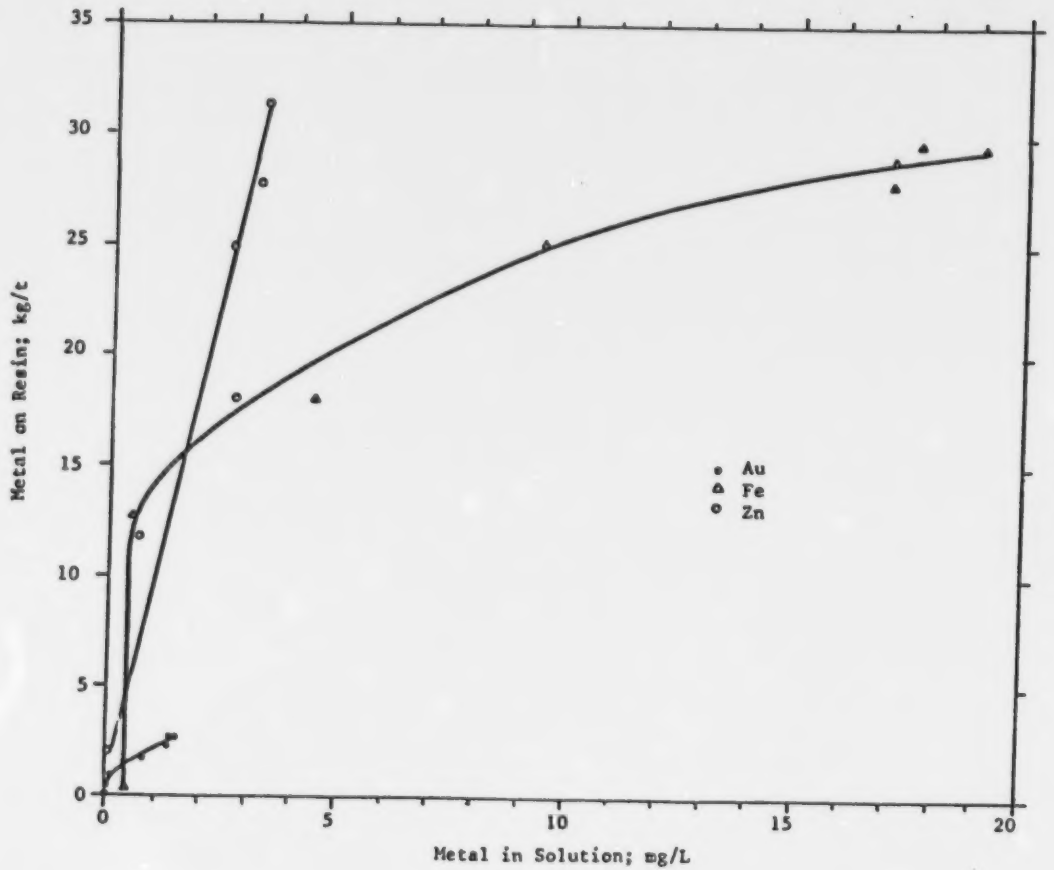

FIGURE 12: TEST 13. LEWATIT MP-500

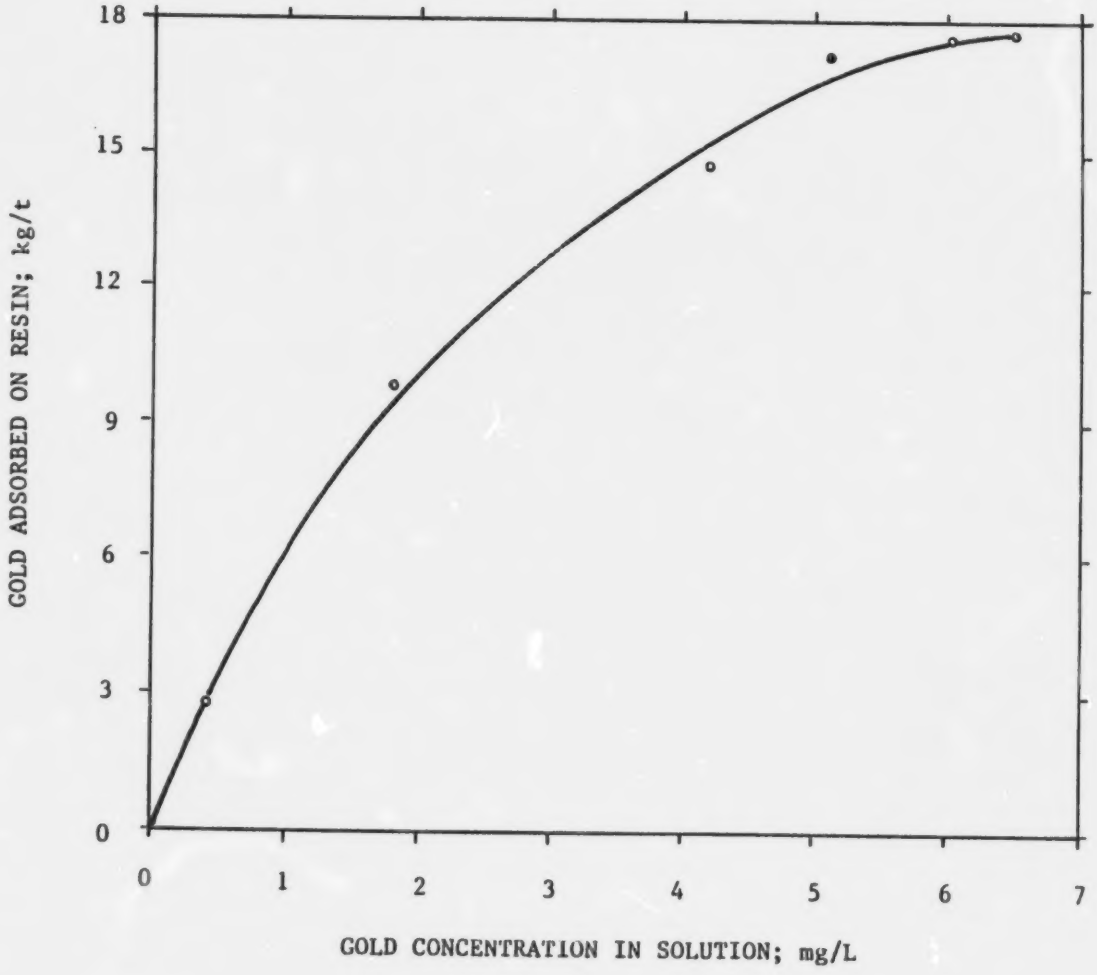

FIGURE 13: TEST 14 DOW XU-40114.00

In addition to Au, when present at significant levels, Ag and Zn also loaded on to the resin.

Silver was observed to load during test 3, reaching a maximum of 0.57 kg/t resin, and then reducing to 0.26 kg/t resin by the final contact. In the remaining four tests, silver was present in the feed below 0.1 ppm, and was difficult to follow accurately. Although not shown in Figures 6 and 9, silver did load to low levels during these tests, 0.21 kg/t and 0.36 kg/t, respectively.

Copper, iron, arsenic and antimony did not load on to XU-40114.00.

Zinc loaded during tests 3, 7 and 12. For test 10 and 14, zinc did not load competitively in the presence of higher feed concentrations of gold (test 14) or higher overall ionic strength of the feed solution (test 10 compared to test 7). For test 3, the final contact was made with a pregnant solution which assayed 4.04 ppm Au and 7.22 ppm Zn, as opposed to the 1.08 ppm Au, 3.73 ppm Zn solution used for the first three contacts. As can be seen in Figure 2, the Zn which was adsorbed by the resin during the initial three contacts was displaced from the resin by the higher Au levels in solution.

Gold loadings from a 45% solids pulp (Test 14) reached 17.8 kg Au/tonne resin (519 oz/t). This was the highest loading observed; the feed assay was also the highest at 6.44 ppm Au. With respect to gold loadings, higher pulp density slurry do not present a problem for this resin. However, resin attrition (see Section 7.0) and the required agitation may increase. Furthermore, resin/pulp separation may present problems since resins tend to float in high density pulp.

MP-500 (Test 5, 9, 13)

This strong base macroporous resin was used during one pregnant solution test (test 5) and two pregnant pulp tests (test 9 and 13). The results provided in Figures 4, 8 and 12 indicate that Cu, Fe and Zn load in addition to gold.

Zinc did not load during test 9 due to the increased competition for sites by the ten-fold higher concentrations of copper and iron. During test 13, copper did not load during stage 1, nor during the subsequent stages where the resin from stage 1 was contacted with fresh pulp. However, copper did load when the pulp from stage 1 was contacted with fresh resin. Although maximum resin loadings and fully stripped solutions with respect to copper were not obtained, and therefore are not included in Figure 12, the resin added during the second contact with fresh resin was loaded to 60 kg Cu/t resin.

Silver and arsenic values in the feed were too low (less than 0.1 and 0.4 ppm, respectively) to follow accurately. Antimony did not load during test 5 and was below detection (0.05 ppm) for tests 9 and 13.

Gold loadings reached 14.1, 4.2 and 2.6 kg Au/tonne resin (411, 122 and 76 oz/t), respectively, for tests 5, 9 and 13. While the feed gold levels were fairly constant for the three tests (1.40 to 1.74 ppm Au), the concentration of the other base metals which load on the resin were much higher in the feed to tests 9 and 13, than in the feed to test 5 (see Table 1).

Dow XU-40139.00 (Test 6)

The results for the second Dow experimental resin tested are provided in Figure 5. In addition to gold, the base metals copper, iron and zinc loaded on to this weak base macroporous resin. Arsenic was present below the detection limit in the feed ($<$0.08 ppm) and silver was present at levels too low to follow accurately (0.027 ppm). Antimony did not load.

While iron and copper were adsorbed by the resin, the loading was not efficient. As noted in Figure 5, the copper levels in the pregnant solution were only reduced from 2.1 to 1.1 ppm after the multi-stage contact. Similarly, iron levels were reduced from 1.6 to 0.4 ppm. Gold loading from the solution reached 12.1 kg Au/tonne resin (353 oz/t).

Duolite FS 137 C (Tests 8 and 11)

Two tests were carried out using the high density resin, test 8 using pregnant solution, and test 11 using pulp. This resin is a strong base resin, and loads copper, iron and zinc in addition to gold. During test 11 (Figure 10), the iron which loaded during the initial stages appeared to be displaced from the resin during subsequent stages. While this is not impossible, it is extremely unlikely since strong base anionic exchange resins tend to have very high affinities for the multivalent ferrocyanide complex. Furthermore, this type of behaviour was not observed during test 8. There is no reasonable explanation for the shape of the iron loading isotherm. Antimony did not load during test 8, and was not present in the feed to test 11 ($<$0.05 ppm). Arsenic and silver were present at levels too low to follow accurately.

Gold loaded to 2.4 and 3.0 kg/t of resin (70 and 87 oz/t), respectively, for tests 8 and 11.

6.1.3.2 Kinetic Studies

During the batch equilibrium testwork, resin and solution or pulp were allowed to react overnight to ensure equilibrium loadings for each contact. In order to obtain information on the kinetics of adsorption, one further test was conducted.

For the kinetic test, 2 mL of resin (Dow XU-40114.00) was contacted with 1.8 L of pregnant solution in an agitated leach vessel. The pH of the solution was maintained at 10.0 and the available cyanide was maintained at 240 ppm. Solution samples were taken after 2, 4, 6, 8 and 24 hours and assayed for gold and zinc.

The results are presented in Figures 14 and 15. After a single contact, gold in solution was reduced from 8.7 to 3.4 ppm after 24 hours. Equilibrium gold loading was 12.9 kg Au/t of resin (376 oz/t) after 24 h.

Forty-one percent of the gold present in solution was adsorbed by the resin within 2 hours. Sixty-eight percent of the equilibrium loading for the single stage was attained within the first 2 hours.

6.1.4 Discussion of Adsorption Testwork

The strong base resins tested (Amberlite IRA-400, Lewatit MP-500 and Duolite ES-137 C) were found to load most base metals competitively with gold. Since gold typically is present at much lower concentrations than base metals in gold-bearing cyanidation leach solutions or pulp, and since aurocyanide is a monovalent anion, $Au(CN)_2^-$, compared to the multivalent base metal cyanide complexes, the majority of the active sites on these resins are occupied by the base metals copper, iron and zinc.

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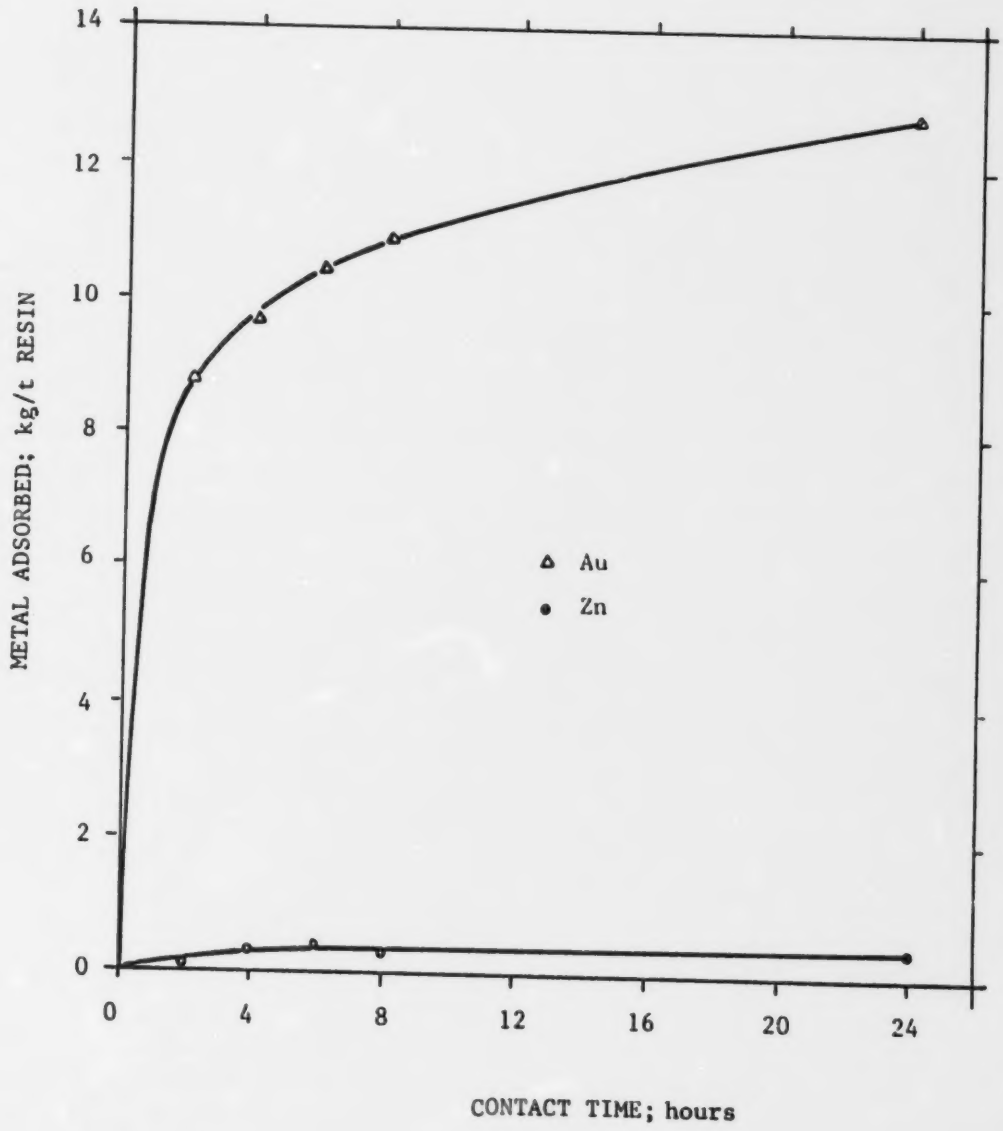

FIGURE 14: ADSORPTION KINETICS - METAL ADSORBED VERSUS CONTACT TIME (RESIN - DOW XU-40114.00)

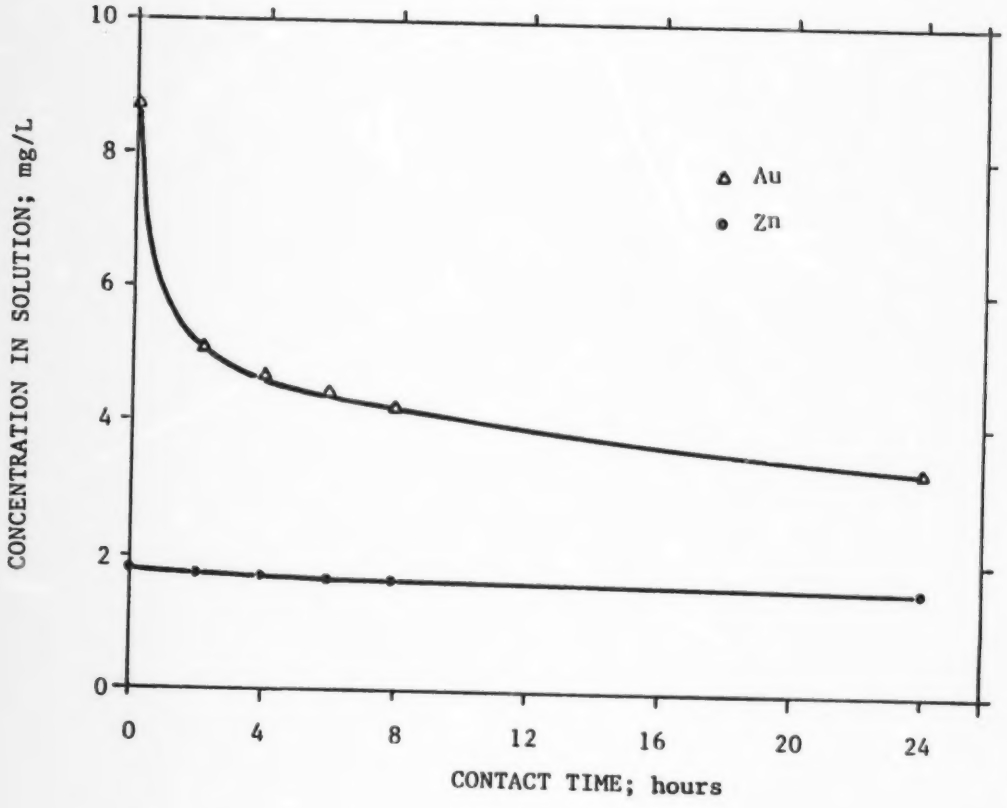

FIGURE 15: ADSORPTION KINETICS - CONCENTRATION IN SOLUTION VERSUS CONTACT TIME (RESIN - DOW XU-40114.00)

The two experimental resins provided by Dow, XU-40114.00 and XU-40139.00 are weak base macroporous resins. These weak base resins are unusual in that they have high apparent pKa's and display high loading capacities in the pH range typical of cyanidation leach solutions. Furthermore, these resins load gold and silver in preference to most base metal cyanide complexes. For the resin XU-40114.00, only zinc competed with the aurocyanide complex. For test 14, which mimicked the conditions typical of carbon-in-pulp circuits (45% solids, pH 10.0), the gold loaded to 17.8 kg of gold/tonne of resin (519 oz/t).

Since this resin offers the possibility of semi-selective adsorption of gold and silver, it was chosen for further testwork.

6.2 Benchscale Elution Testwork

Elution testwork was carried out on the most promising resin from the benchscale loading tests, the Dow resin XU-40114.00. This resin is a weak base resin (see Section 3.2). One important advantage of weak base resins over strong base resins is that they are readily eluted at pH values higher than the pKa of the resin. At higher pH values, the functional group of the resin is deprotonated and present in the free base form, and therefore has no affinity for anions.

Two elution tests were carried out on XU-40114.00 resin which had been loaded during the benchscale loading testwork. The methodology and results are provided below. Additional elution testwork was carried out in conjunction with the mini-plant operation, and is presented in Section 7.0.

6.2.1 Methodology

The benchscale elution testwork was carried out batchwise in a beaker. Only small resin samples were available from the benchscale loading work (2 mL per test). While the results do indicate the best eluant for removal and recovery of the three metals which loaded onto the Dow XU-40114.00 resin (gold, silver and zinc), the minimal number of bed volumes of eluant required for complete desorption could not be obtained from such small resin samples. This information was obtained from the larger loaded resin samples produced during the mini-plant operation (see Section 7.0).

The resin samples were contacted with the eluant batchwise for 30 minutes, in a beaker with agitation. The eluate was decanted and assayed for metals. The resin was contacted with the next batch of eluant. For the two benchscale elution tests (tests 1 and 2), resin produced during benchscale loading tests 3 and 7 was used, respectively.

The results are presented below for each elution test.

6.2.2. Experimental Results

Elution Test 1

The first elution test was carried out with 2 mL of resin from benchscale loading test 3. In total, the loaded resin was subjected to eleven stages of batch elution. A description of the eluant used for each stage, and the volume of eluant is provided below in Table 2.

Table 2

EXPERIMENTAL CONDITIONS AND RESULTS OF BATCH ELUTION TEST 1

Stage	Eluant		Metals Recovered, ppm		
	Type	Vol., mL	Au	Ag	Zn
1	1% NaOH	50	21.1	4.29	84.2
2	1% NaOH	50	12.7	1.02	6.15
3	1% NaOH	50	9.16	0.27	0.53
4	1% NaOH	50	6.84	<0.004	<0.006
5	1% NaOH	50	6.09	<0.004	<0.006
6	1% NaOH, 0.2% NaCN	20	11.3	-	0.99
7	1% NaOH, 0.2% NaCN, 90 to 93°C	15	55.9	-	0.69
8	1% NaOH, 0.2% NaCN, 20% Methanol	20	6.29	-	0.38
9	1% NaOH 0.2% NaCN 90 to 93°C	20	13.0	-	0.58
10	1% NaOH 0.2% NaCN 90 to 93°C	20	17.1	-	0.77
11	1% NaOH 0.2% NaCN 90 to 93°C	20	14.2	-	<0.006
Total Loaded, mg			4.74	0.21	5.15
Total Recovered, mg			4.87	0.28	4.61
Mass Balance, %			103	133	90

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WD1

For the first five contacts, 1% NaOH was used. As incomplete gold recovery was obtained after 5 contacts of 25 bed volumes each, (see Table 2) it was decided to test the methodology commonly used to recover gold from carbon. The Zadra method (17) utilizes a 1% NaOH, 0.2% NaCN solution maintained at 90 to 93°C. In order to determine if the use of increased temperatures was necessary, stage 6 tested a solution of 1% NaOH, 0.2% NaCN. For test 7, the same eluant was used, but the temperature was maintained at 90 to 93°C.

An adaptation of the Zadra method (18) involves the addition of water soluble organic compounds such as alcohols or ketones. In particular, 20% (V/V) has been found (18) to be effective for the recovery of gold from carbon. This method was tested during stage 8. The eluant which was the most promising was then used during three more stages of batch elution (stages 9 to 11) in order to fully recover the gold, silver and zinc.

The data provided in Table 2 indicate that an eluant of 1% NaOH, 0.2% NaCN (stage 6) is more effective than 1% NaOH alone (see stage 1 to 5). Furthermore, the same eluant heated to 90 to 93°C is even more effective (see stage 7).

The additional of 20% methanol (V/V) to the room temperature eluant (1% NaOH, 0.2% NaCN) was less efficient (stage 8) than the heated eluant without methanol (stages 9 to 11).

It is concluded that the Zadra eluant (17), which currently is being used for carbon stripping is the best eluant tested for the recovery of gold from the Dow resin XU-40114.00.

The percent recoveries for Au, Ag and Zn based on the loading data presented in Section 6.1.3, are also provided in Table 2. In addition to gold, silver and zinc were completely recovered during the eleven stages of elution, within experimental error.

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WD1

Copper and iron, which were not observed to load on the resin (within experimental error) during the loading testwork, were also assayed in the eluate. In total, 0.25 mg Cu and 0.31 mg Fe were recovered in the eluate, indicating low level adsorption by the resin.

Elution Test 2

The second elution test was carried out on 2 mL of resin from benchscale loading test 7. In total, the resin was contacted with ten stages of batch elution using 1% NaOH, 0.2% NaCN at 90 to 93°C. For each stage, 20 mL of eluant (10 bed volumes) was used. The results are presented in Table 3.

Table 3

RESULTS OF BATCH ELUTION TEST 2

Stage	Volume of Eluate mL	Metal Recovered, ppm Gold	Silver	Zinc
1	15	406	4.24	148
2	17	91	1.01	16
3	17	100	0.58	2.8
4	17	31	0.23	0.23
5	18	24	0.30	0.57
6	18	23	0.17	0.006
7	15	23	0.31	0.006
8	20	14	-	-
9	20	13	-	-
10	20	12	-	-
Total Loaded, mg		12.61	0.17	2.00
Total Recovered, mg		11.85	0.11	2.55
% Recovered		94	65	128

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As indicated above, 94 percent recovery of gold was obtained after batch contact with 100 bed volumes of eluant. While indicating that good recoveries may be obtained, this does not represent minimal bed volumes due to the small resin sample used for this testwork.

In addition, 0.5 mg of iron and 0.5 mg of copper was recovered in the eluate, indicating low level loadings for these two base metals.

More information on the elution procedure was obtained using the larger loaded resin samples obtained from the mini-plant operation. See Section 7.0 for elution isotherms and minimal bed volumes of eluant.

6.2.3 Discussion of Elution Testwork

The resin chosen for further investigation on the basis of the benchscale loading testwork, Dow XU-40114.00, is a weak base resin. As such, elution is feasible using an alkaline eluant at pH levels greater than 10.5. However, the elution testwork has indicated that elution is improved by the addition of 0.2% NaCN to the caustic eluant, and by heating the eluant to 90 to 93^{o}C.

Since this is a method currently utilized by some mills which have carbon-in-pulp circuits, for carbon stripping, this would greatly facilitate the conversion of CIP circuits to resin-in-pulp. However, it remains to be determined how well the resin would stand up to treatment at such elevated temperatures.

7.0 OPTIMIZATION OF R.I.P. FLOWSHEET

In order to optimize the resin-in-pulp flowsheet, a mini-plant operation was undertaken. The mini-plant was operated for a total of 90 hours between May 16 and May 23, 1986, in the pilot plant facilities of Witteck Development.

The objectives of the mini-plant were:

- identify potential flowsheet problems
- investigate resin/pulp separation
- investigate resin attrition
- determine stage requirements
- investigate resin scaling or poisoning

The size of the mini-plant operation was 1 kg of solid per hour as a 41% solids slurry.

Preparation and characterization of the feed pulp is described in Section 7.1. Preparation of the resin is provided in Section 7.2. A description of the mini-plant equipment and operational procedures is detailed in Section 7.3. The experimental data and discussion are presented in Sections 7.4 and 7.5, respectively.

7.1 Preparation and Characterization of Feed Pulp

As described in Section 5.1, the pregnant leach slurry used for the mini-plant was obtained from Teck-Corona Ltd. In preparation for the mini-plant, a brief cyanidation leach was carried out to ensure complete solubilization of the gold. During the leach, the pH of the slurry was maintained above 10.5 by the addition of lime, and the available cyanide was maintained above 0.2 gpl by the addition of NaCN. The feed slurry contained 41% solids (pulp density = 1365 g/L; S.G. of solids = 2.75).

Screen analyses of the feed pulp is provided below in Table 4.

Table 4

SIZE DISTRIBUTION

Mesh Size	Cumulative % Passing
100	99.7
150	98.6
200	96.3
325	68.3
400	60.4

Chemical analyses of the pregnant solution and solids is provided in Table 5.

Table 5

CHEMICAL ANALYSES OF FEED SLURRY

	Pregnant Solution, ppm	Solids, %
Sb	1.78	<0.008
As	0.001	0.037
Co	1.53	<0.005
Cu	13.2	<0.003
Au	3.51	<0.008
Fe	18.1	2.29
Pb	0.01	0.001
Hg	0.044	0.021
Mo	5.62	0.043
Ni	0.98	<0.006
Ag	0.20	0.003
Zn	0.77	0.011

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WD1

The pH of the pulp was 11.7. This was due to stabilization of the pulp prior to shipping. After the first solution profile, the pH was decreased, maintained between 9.5 and 10.0 by the addition of sulphuric acid.

The feed slurry was prescreened through a 100 mesh screen in order to remove tramp material.

7.2 Preparation of the Resin

The Dow experimental resin XU-40114.00, which was selected during the benchscale testwork, was received from Dow in the chloride form. The resin was converted to the hydroxide form, and prescreened to 100% minus 28 mesh in order to remove the fines.

7.3 Equipment and Methodology

7.3.1 Mini-Plant Equipment

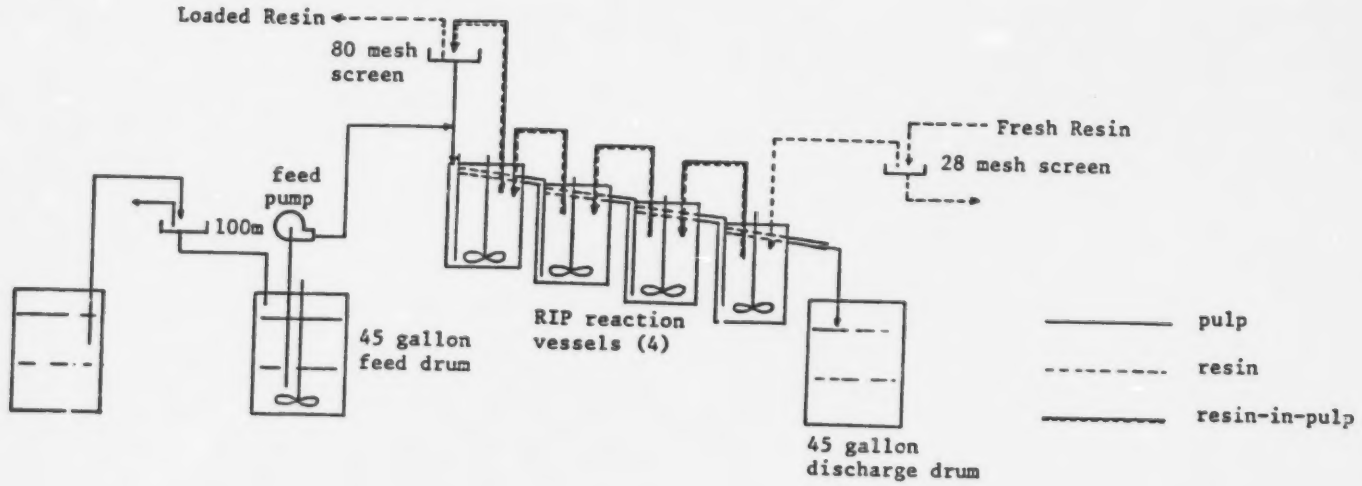
A complete flowsheet of the RIP pilot plant is presented in Figure 16. The pilot plant was made up entirely of equipment and materials available in the Witteck pilot plant area. A description of the mini-plant equipment is provided below.

Feed Tank:

The feed tank consisted of a 170 L drum equipped with baffles and an agitator.

Feed Pump:

A 7016 Masterflex pump with speed controller was used to pump the slurry to the R.I.P. circuit.



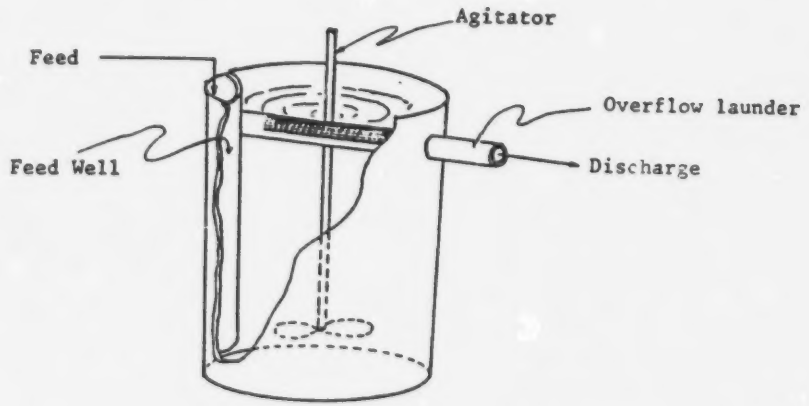


FIGURE 16: RIP CIRCUIT AND REACTION VESSEL

R.I.P. Circuit:

The RIP circuit consisted of four 5 L vessels arranged in cascade. Each vessel was equipped with an overflow launder (2.5 cm diameter). A longitudinal section of each launder had been replaced with a 40 mesh nylon screen, allowing the pulp to advance by gravity flow, but retaining the resin. Feed slurry was fed directly to the bottom of each vessel through a 2.5 cm diameter feed tube.

Reaction Vessel Agitator:

Each reaction vessel was equipped with a variable speed "Caframo" laboratory agitator. The impellers were teflon coated.

Discharge Tank:

The barren slurry overflowed by gravity into a 170 L drum.

7.3.2 Mini-Plant Methodology

7.3.2.1 Adsorption

Operation

Operation of the mini-plant was basically continuous. Slurry was pumped from the agitated feed tank into the first stage of the RIP circuit. With the exception of the last 12 hours of operation, the retention time in each stage of the four stage reaction vessel was 1.78 hours. The slurry exiting the circuit overflowed in a 170 L drum.

The flow of resin was countercurrent to the flow of solution (see Figure 16). Resin was advanced manually twice during the campaign. On the first occasion, the first stage was withdrawn from the adsorption circuit and drained over a 40 mesh screen for recovery of the loaded resin. The second, third and fourth stages were moved into the first, second and third positions, respectively. The original first stage pulp was recharged with fresh resin and moved into the final position.

On the second occasion, after screening (40 mesh) the first stage slurry, the pulp was returned to the first stage vessel. The three subsequent stages were also screened and the pulp returned to the original vessel. The resin content of each vessel was advanced one stage. First stage resin reported to elution and analysis. Fresh resin was added to the fourth stage.

Sampling:

Sampling was confined largely to the solution content of the four stages of RIP. Profile samples were taken hourly and composited over six hours. Solution samples were assayed routinely for gold, and periodically for zinc. Prior to shut-down, samples of the feed solution, the four stages of RIP solutions, and barren solution were assayed for a complete list of metals (antimony, arsenic, cobalt, copper, gold, iron, lead, mercury, molybdenum, nickel, silver and zinc). The size of the mini-plant operation restricted the size of samples which could be taken from each stage without disrupting the operation of subsequent stages. Consequently, gold samples were assayed directly by DCP without a preconcentration step. A conservative detection limit of <0.03 ppm has been quoted. During Phase II, a pilot demonstration, the size of operation would allow for larger samples to be taken, and a detection limit of <0.01 ppm Au will be feasible.

A representative sample of the slurry feed solids also was assayed for the eleven metals listed above.

Prior to shut-down, a profile set of resin samples were removed from each stage of the circuit. These resin samples, along with the two resin samples removed from the circuit during resin advancement, were assayed for the complete list of twelve metals given above.

Flow Rates:

The mini-plant was designed for feed rate of 1 kg solids per hour. The slurry pulp density was 1.365 kg slurry per litre (41% solids). Therefore, slurry was fed to the RIP circuit at a rate of 30 mL/min. Each stage contained 3.2 L to the overflow level. Therefore, the retention time was 1.78 hours per stage.

For the final 12 hours of operation, the slurry feed rate was increased to 60 mL/min (0.89 h/stage) to ascertain if shorter retention times could be utilized.

Stage Requirements:

Loading isotherms obtained during the benchscale program were used to estimate the stage requirements for a countercurrent RIP circuit. A McCabe-Thiele diagram was constructed, assuming a conservative equilibrium loading capacity of 15 kg Au/t resin (438 oz/t) and the feed solution assay of 3.51 ppm Au. As shown in Figure 17, four stages of resin in pulp were determined to be sufficient.

Resin Requirements:

Resin requirements per stage were determined assuming that resin advancement would occur once every 24 h. At 3.51 ppm Au in solution and a feed rate of 24.2 mL solution per minute (30 mL slurry per minute), 122 mg of gold would be fed to the circuit every 24 h. Assuming an equilibrium loading capacity of 15 kg Au/t of resin, each stage required 8.2 g resin.

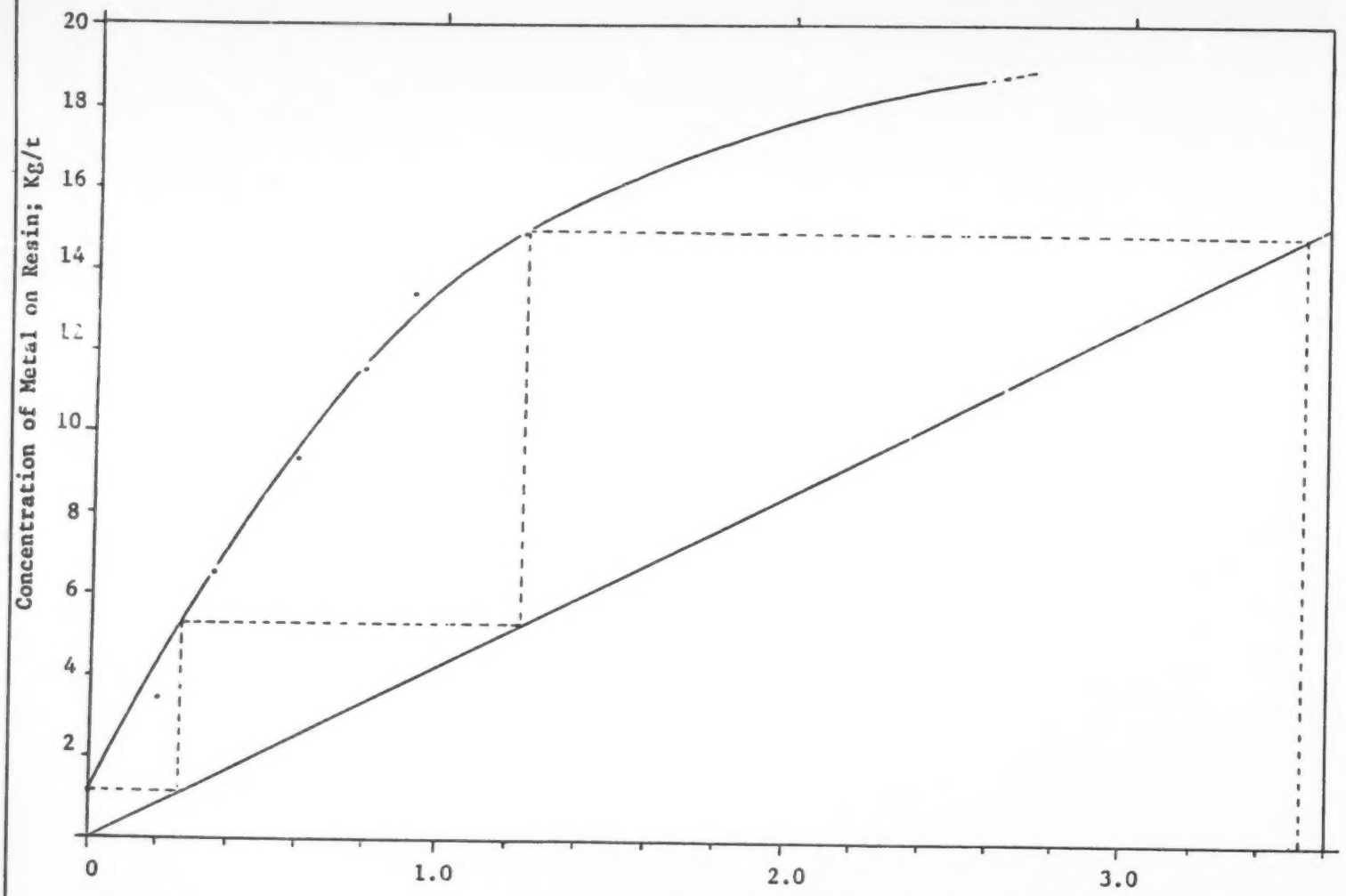


Figure 17: Stage Requirements for Resin-in-Pulp Mini-plant (McCabe-Thiele Diagram assuming gold loadings of 15 Kg/t and head solution of 3.51 ppm Au.)

7.3.2.2 Elution

A batch elution test was carried out on a six gram sample of resin from the second resin advance. The resin was agitated in a one bed volume (14 mL) sample of eluant in a 50 mL beaker. The beaker was covered with a rubber stopper equipped with a thermometer and a small air vent tube to minimize evaporation. The eluant was 1% NaOH, 1% NaCN in distilled water. After two hours, the resin was separated, and washed with one bed volume of water. The eluate and wash water were combined in a 100 mL volumetric flask and assayed for gold, iron and zinc. The resin was recontacted with fresh eluant as described above. In total, the resin was contacted 15 times with one bed volume of eluant per contact. For the first two contacts, the temperature of the eluant and wash water were maintained at 60 to 63°C. For the remaining 13 contacts, the temperature was increased to 90 to 93°C.

7.4 Experimental Results of Mini-Plant Campaign

7.4.1 Adsorption

The mini-plant was operated for 24 hours on May 15-16, 1986, and again on May 20. The circuit was operated continuously from noon on May 21 to midnight on May 23.

Resin was advanced at noon on May 21st and at 0600 on May 23. Solution profile assays for stages 1 to 4 are provided in Table 6 and Figure 18. As indicated in Table 5 above, the feed solution assayed 3.51 ppm Au and 0.77 ppm Zn.

Table 6

CONCENTRATION OF GOLD AND ZINC IN SOLUTION (ppm)

		Stage							
		1		2		3		4	
Date	Time	Au	Zn	Au	Zn	Au	Zn	Au	Zn
16	0000-0500	0.91	-	0.22	-	<0.03	-	<0.03	-
20	1100	1.01	-	0.27	-	0.11	-	0.09	-
----------	----------	resin advanced							
21	1200-1700	0.55	-	<0.03	-	<0.03	-	<0.03	-
	1500	0.72	-	0.12	-	<0.03	-	<0.03	-
	1800-2300	0.84	-	0.16	-	<0.03	-	<0.03	-
22	0000-0500	1.04	<0.05	0.32	<0.05	<0.03	<0.05	<0.03	<0.05
	0600-1100	1.21	<0.05	0.48	<0.05	<0.03	<0.05	<0.03	<0.05
	1200-1700	1.73	0.16	0.50	<0.05	0.16	<0.05	0.04	<0.05
	1800-2300	1.95	1.21	0.57	0.71	0.18	<0.05	0.09	<0.05
23	0000-0500	2.28	-	0.82	-	0.43	-	0.29	-
----------	----------	resin advanced							
	0600-1100	2.49	-	0.92	-	0.31	-	0.08	-
	1500-1700	2.09	-	1.03	-	0.51	-	0.27	-
	1800-2000	2.42	-	1.43	-	0.84	-	0.46	-
	2100-2300	2.52	-	1.64	-	0.79	-	0.61	-

By the third and fourth stages, gold in solution was typically less than 0.03 ppm, and zinc was less than 0.05 ppm. Higher gold levels in solution on the morning of May 23, indicated that the resin was loaded to breakthrough capacity in stage 4. The resin was advanced at 0600 h on May 23rd, 42 hours after the first resin advancement.

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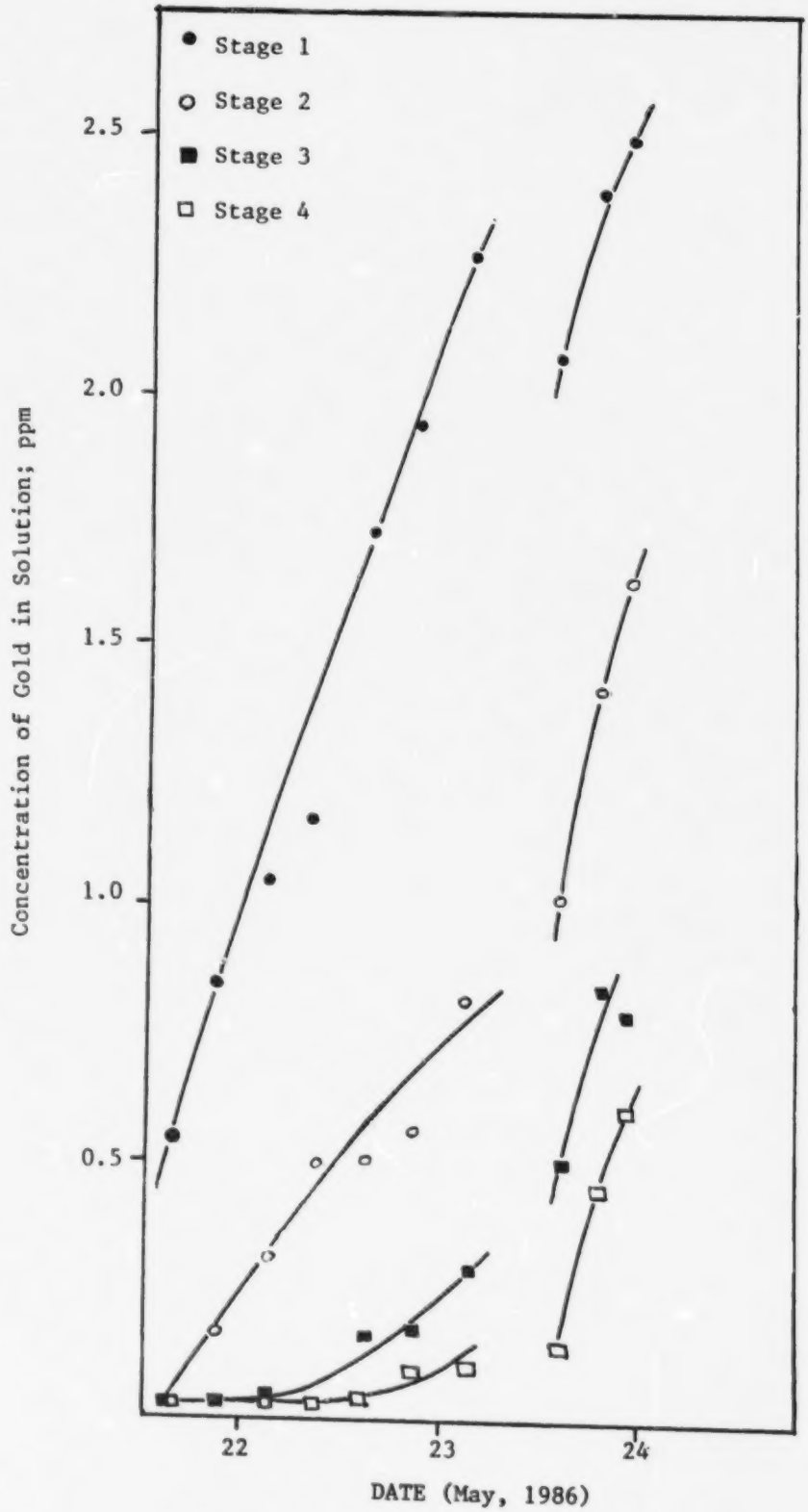

Figure 10. Solution Profile Gold Analysis

For the last 12 hours of operation, the slurry feed rate was increased from 30 mL/min to 60 mL/min, reducing the retention time per stage from 1.78 hours to 0.89 hours. As shown in Table 6 and Figure 18, this retention time was insufficient to produce barren solution containing less than 0.03 ppm Au.

At shutdown, both solution and resin samples were assayed for gold, in order to produce loading a isotherm. The results are presented in Table 7 and Figure 19.

Table 7

RESIN AND SOLUTION ASSAYS

	Au Concentration in Solution (ppm) and on Resin (kg/t)			
Sample *	Stage 1	Stage 2	Stage 3	Stage 4
Solution	1.98	1.29	0.80	0.45
Resin	10.2	3.7	1.8	1.8

These samples were taken at the end of the mini-plant operation, when the feed rate was doubled, and the gold assays in stage 4 had increased to 0.45 ppm. Consequently, the isotherm produced does not display the classical shape of an adsorption isotherm. Resin removed from Stage 1 was loaded to 10.2 kg Au/t (298 oz/t).

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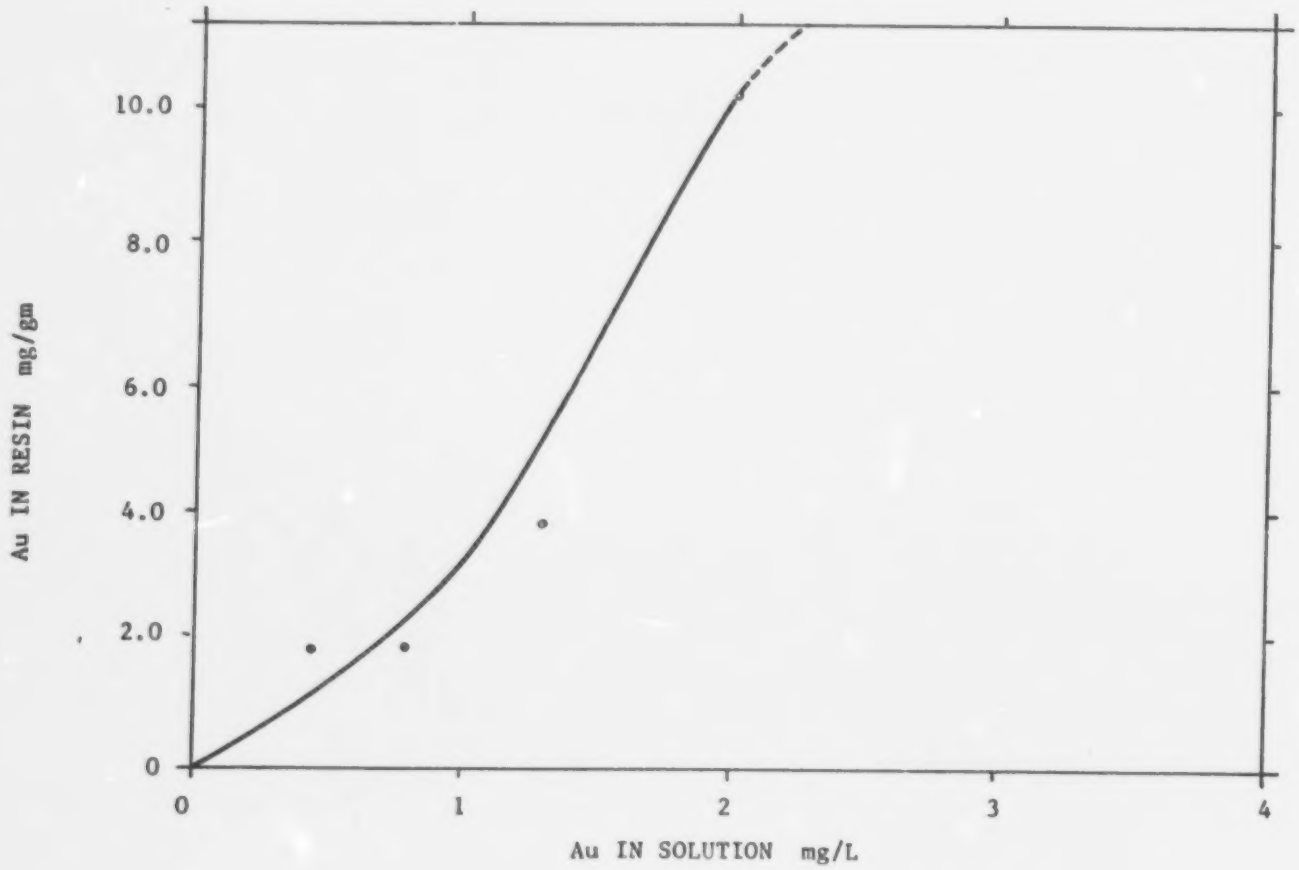

FIGURE 19: ADSORPTION ISOTHERM

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At shut-down, the profile solution samples for stages 1 to 4 solutions, were assayed for a complete range of elements. At the same time, resin samples were removed from each stage of the RIP circuit, and were assayed for the same elements. In addition, a composite sample of the feed solution and a composite sample of the barren discharge solution was assayed for the same elements. The results, along with the analyses of the two resins sample from resin advancement, are provided in Table 8.

The results indicate that in addition to gold and zinc, nickel also loaded on to the resin. In stage 4, after the bulk of the gold had been removed from the pulp during the first three stages, zinc loaded to 9.1 kg/t and gold loaded to only 1.8 kg/t in stage 4. In contrast, by the time the resin was removed from the adsorption train (2nd advance), zinc loadings were only 2.0 kg/t, whereas gold was loaded to 10.5 kg/t (306 oz/t). In agreement with the benchscale studies, it appears that gold is adsorbed preferentially to the base metals, including zinc during the initial stages of RIP, and that the zinc adsorbed during stage 4 may be displaced by gold when contacted with the higher gold levels present in stages 1 and 2. Although the solution assays provided in Table 8 imply nickel adsorption, the resin analyses are fairly constant, showing no build-up of nickel through the circuit.

Arsenic and lead were not present in the feed solution. Antimony, cobalt and mercury were not adsorbed. Although the solution assays did not imply adsorption of copper, molybdenum and silver, the resin analyses did indicate low level loadings by the time the resin was removed from the RIP circuit (0.4 kg Cu/t; 0.3 kg Mo/t; 0.1 kg Ag/t).

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Table 8

SOLUTION (ppm) AND RESIN (kg/t) ASSAYS FROM RIP MINI-PLANT

	Au	Zn	Cu	Fe	Ni	As	Sb	Mo	Hg	Pb	Ag	Co
Solution:												
RIP Feed	3.51	0.77	13.2	18.1	0.98	<0.01	1.8	5.6	0.04	<0.01	0.16	0.15
Stage 1	1.76	<0.03	-	17.6	0.68	-	-	-	0.11	-	0.21	0.10
Stage 2	1.04	<0.03	-	16.4	0.63	-	-	-	0.04	-	0.22	0.15
Stage 3	0.59	<0.03	-	15.6	0.60	-	-	-	0.02	-	0.23	0.12
Stage 4	0.30	<0.03	-	14.6	0.52	-	-	-	0.03	-	0.20	0.12
RIP Discharge	0.30	<0.03	13.7	22.8	0.40	<0.01	2.0	5.6	<0.01	<0.01	0.14	0.10
Resin:												
1st advance	8.5	2.7	1.4	7.3	0.3	0.03	0.07	0.22	0.02	0.14	0.14	0.03
2nd advance	10.5	2.0	0.4	2.5	0.3	0.03	0.05	0.31	0.03	0.13	0.11	0.03
Stage 1	10.2	4.8	0.8	10.0	0.2	0.03	0.06	0.41	0.04	0.32	0.16	0.02
Stage 2	3.7	2.9	1.5	8.3	0.4	0.01	0.04	0.33	0.03	0.10	0.20	0.03
Stage 3	1.8	4.0	2.0	8.3	0.4	0.01	0.05	0.40	0.03	0.09	0.20	0.03
Stage 4	1.8	9.1	4.6	7.3	0.2	0.01	0.04	0.38	0.05	0.10	0.15	0.02

The apparent high iron loadings were due to the inclusion of scale from the feed drum, particles of which were visible in the resin samples which were submitted for analysis. Solution analyses, however, do not rule out adsorption of iron by the resin during the four stages of RIP. The higher assay in the discharge filtrate is most likely due to iron from the discharge drum.

The gold assays at shut-down are also provided in Table 8, both in solution and adsorbed onto the resin. Gold loadings of greater than 10 kg Au/t (292 oz/t) of resin were obtained.

7.4.2 Elution

A sample of resin from the second resin advance was eluted batchwise as described in Section 7.3.2.2. above. The resin was contacted with 15 stages of eluant (1% NaCN, 1% NaOH). The results are presented in Table 9 and Figure 20, and indicate that 94% of Au, and 89% of the Zn can be recovered within 15 bed volumes. Considering that the total recovery is the sum of 10 to 15 assays, each of which typically has a 5% error associated with it, complete recovery of gold and zinc was achieved, within experimental error.

After elution, the resin was assayed for metals in order to confirm the recovery of gold and zinc, and to determine if any metal which was adsorbed to low levels by the resin, remained on the resin after elution. The results, provided in Table 10, indicate that 98% of the gold and 98% of the zinc was removed from the resin during elution. Furthermore, none of the metals present acted as resin poisoning agents.

Table 9

ELUTION TEST DATA AND METAL BALANCE

Resin Head Assays (mg):	Au: 63	Zn: 12
Eluted Resin Assay (mg):	Au: 1.52	Zn: 0.3
Percent Remaining on Resin:	Au: 2.4%	Zn: 2.5%

Concentrated Eluate Analysis:

Element	Au	Zn
Bed Volumes	(mg)	(mg)
1	2.53	5.31
2	8.56	2.50
3	19.29	1.99
4	8.57	0.53
5	5.10	0.15
6	3.82	0.06
7	3.13	0.03
8	2.26	0.03
9	1.58	0.03
10	1.34	0.02
11	0.93	-
12	0.72	-
13	0.49	-
14	0.39	-
15	0.44	-
TOTAL (mg)	59.15	10.65
RECOVERY (%)	94	89

* A large part of the iron in the resin head assay was the result of debris rather than adsorbed iron.

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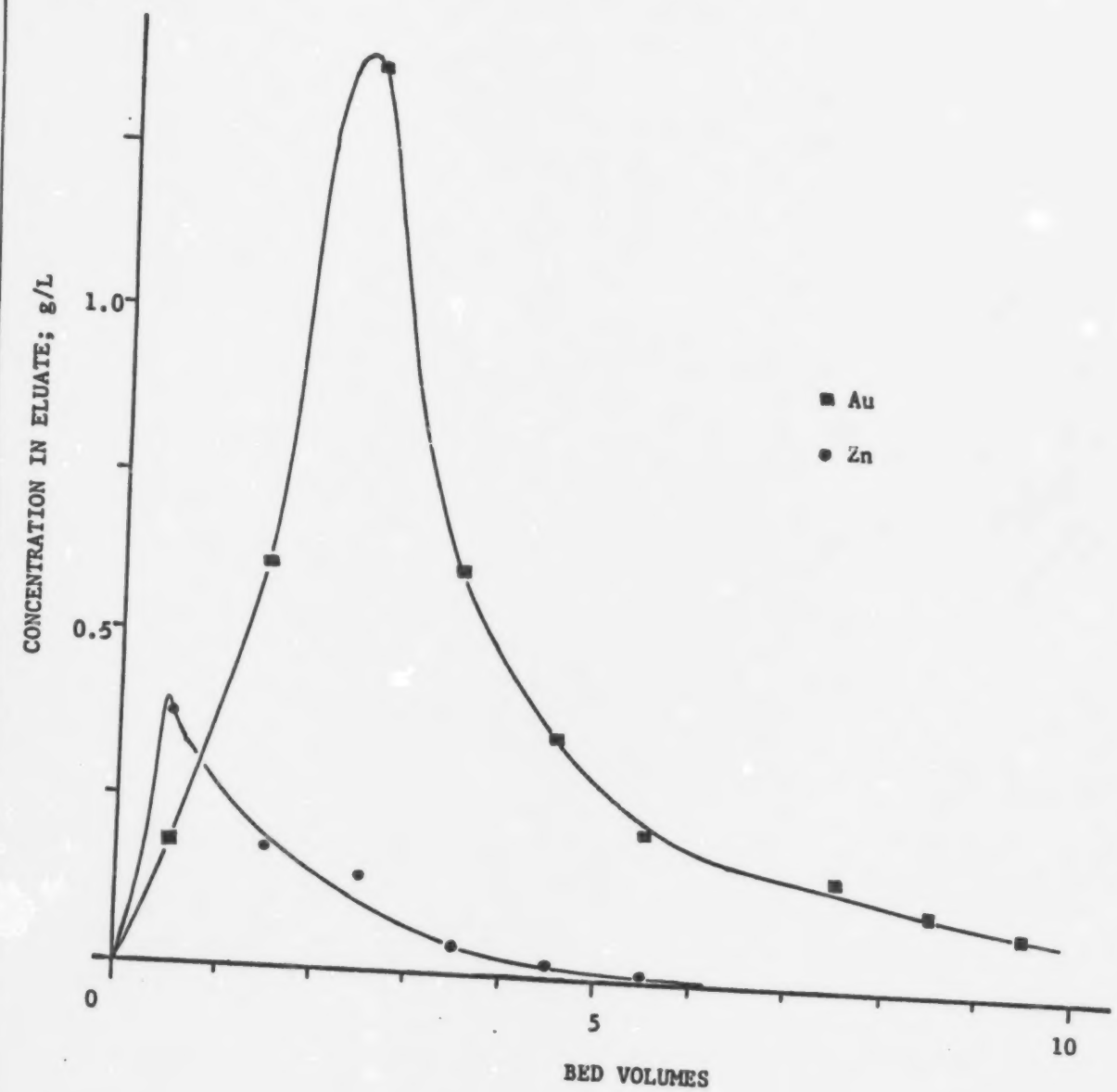

FIGURE 20 ELUTION ISOTHERM

Table 10

ANALYSES OF ELUTED RESIN (kg/t)

Cu	Au	Fe	Ni	Ag	Zn
0.2	0.25	0.08	0.02	<0.003	0.05

7.4.3 Resin Attrition

A sample of fresh resin and loaded resin from the second advance were examined by scanning electron microscope. At a 200 fold magnification, the striking feature of the fresh resin is the very smooth blemish free spherical surface of the beads, as shown in Figure 21. Figure 22 shows a bead surface after approximately 90 hours exposure to agitated solids in pulp. The surface is covered with shallow irregular pits which are the result of attrition.

The mini-plant was operated for a total of 14.4 cycles. At this stage, it remains unknown if the amount of attrition observed is simply the loss of surface powders from the fresh resin, and therefore further attrition would not be observed during subsequent cycles, or alternatively, if the same degree of attrition will continue during subsequent cycles, resulting in the eventual need to replace the lost resin.

Phase II, Pilot Plant Studies, will utilize a larger resin inventory. It is recommended that periodic sampling of the resin be performed to determine if attrition halts once the resin has been through the initial few cycles. With the larger resin inventory, screen analyses along with SEM would be feasible, and would allow for the observation of pulverized resin, if present.

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Figure 21: Fresh XU-40114.00 Resin

Figure 22: Fully loaded XU-40114.00 Resin

7.4.4 Resin Scaling

Scaling of carbon due to calcium typically is determined by measuring the density of the used carbon and comparing it to that of fresh carbon. Scaling is indicated by an increase in the density of the used carbon with respect to that of the fresh carbon. Accordingly, the same procedure was employed for resin. The eluted resin from the second resin advance, reconverted to the hydroxide form, had a density of 0.45 g/mL compared to 0.48 g/mL for fresh resin also in the hydroxide form. Therefore, it is concluded that scaling of the resin did not occur to any detectable extent.

7.4.5 Overall Gold Balance

The mini-plant campaign was operated for a total of 90 hours, at a slurry feed rate of 30 mL/min for the first 78 hours and then at a slurry feed rate of 60 mL/min for the final 12 hours. Therefore, a total of 183.6 L of slurry was fed to the RIP circuit. At a specific gravity of 1.365 kg slurry/L and 41% solids, this means a total of 147.8 L of gold-bearing solution was fed to the circuit. At 3.51 mg Au/L solution, 519 mg of gold was processed through the RIP circuit.

At shut-down, a composite sample of the barren filtrate assayed 0.3 mg/L gold, due predominantly to the last 12 h of operation at the increased feed rate. Therefore, 44 mg of gold remained in the barren at shut-down. The gold adsorbed by the resin (see Table 8) accounts for a further 421 mg of gold, for a total gold recovery of 465 mg, or 90% of the gold added. This mass balance does not include the gold removed from the circuit by sampling.

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8.0 CONCLUSIONS AND RECOMMENDATIONS

During the benchscale testwork, resin loaded gold to 17.8 kg/tonne or 519 oz/t. During the continuous operation of the mini-plant campaign, the resin loaded to 10.5 kg/t or 306 oz/t. These results are very encouraging compared to carbon loading; a representative from Teck-Corona indicated that at the time of this test program, carbon loadings were typically 300 oz/t, and loadings in the range of 200 to 250 oz/t are common.

The most promising resin, Dow XU-40114.00, showed a selectivity for gold over base metals, allowing for the high equilibrium loading capacities given above. This factor alone overcomes one of the major concerns for gold recovery using resins, i.e., that most of the resin capacity is consumed by the base metal anions in the feed solution.

Gold barren solutions after resin-in-pulp contained less than the conservative detection limit of 0.03 mg/L Au. During Phase II, a pilot demonstration, the size of operation would allow for larger samples to be taken. With a preconcentration step prior to assaying, a detection limit of 0.01 ppm Au will be feasible. Only four stages of RIP were required (1.78 h/stage) compared to the six stages typical of CIP (7 h/stage at Teck-Corona).

Although the resin is less dense than activated carbon, the resin did not appear to float on the surface of the pulp. Resin/pulp separation was carried out easily using a 40 mesh screen to retain the resin beads.

The resin was eluted efficiently under the conditions typical of CIP. The resin was not scaled nor poisoned following the 90 hour mini-plant campaign. However, some attrition of the resin due to agitation during the adsorption cycle was observed.

In future testwork, the gold could be recovered from the eluate by electrowinning in a closed electroelution process. With this adaptation, perhaps lower temperatures could be used during elution, thereby eliminating or reducing the resin breakdown which would occur due to elution at such elevated temperatures.

Due to these encouraging results, it is recommended that Phase II - Pilot Plant Studies be carried out. Although the mini-plant operation provided data on gold and base metals loadings, barren levels and elution techniques, many questions remain unanswered. Although qualitative information was obtained, the size and duration of the mini-plant campaign limited the amount of quantitative information which could be obtained on the following items:

- scaling of resins by calcium;

- poisoning of resins by flotation reagents or organic solvents;

- optimal technology available for continuous resin/pulp separation (see brochure for Delkor Linear Screens provided in Appendix II);

- long-term attrition of resin due to agitation in pulp.

Due to the limited length of the mini-plant campaign, and the need for loaded resin samples for elution testwork, used eluted resin was not recycled to the RIP circuit. Although analysis of the eluted resin did not indicate poisoning by any of the base metals, a pilot scale operation, where resin could be recycled, is required to observe any long term poisoning action. Furthermore, reuse of eluted resin would indicate if resin breakdown is occurring during the elution step.

In addition, further contact with the resin manufacturers is necessary to ascertain if the experimental resin, which seems so promising, could be made available in a larger, more dense, bead, thereby simplifying the pulp/resin separation process. Furthermore, Dow has indicated that it may be feasible to produce a "harder" resin bead, more resistant to attrition caused by agitation in pulp.

One parameter which has not yet been considered is the build-up of impurities in the RIP circuit. During Phase I, zinc loaded to some extent on the resin along with the gold. During elution, zinc is recovered in the eluate with the gold. In a closed electroelution circuit, the gold would be removed continuously from the eluate during stripping, but the zinc would build-up. A bleed would be required to maintain the zinc at an as-yet undetermined optimal level. In addition to zinc, a build-up of other trace elements may become evident during pilot plant operation.

The electrowinning of gold has yet to be evaluted in conjunction with the RIP process.

Finally, a pilot plant operation is mandatory to provide data adequate for scale-up.

APPENDIX I

ANALYTICAL PROCEDURES

APPENDIX I

ANALYTICAL PROCEDURES

All solution analyses were performed in-house. Metals (Sb, As, Co, Cu, Au, Fe, Pb, Hg, Mo, Ni, Ag, Zn) were assayed directly either by Atomic Adsorption (AA) or by Direct Coupled Plasma (DCP). Low level arsenic (less than 0.5 ppm) was assayed colourimetrically using pyridine/silver diethyldithiocarbamate reagent after HCl/Zn arsine evolution.

Resin samples were acid digested and assayed by AA or DCP as above for base metals. Resin were assayed for gold and silver by fire assay, followed by digestion and finished using AA or DCP.

APPENDIX II

DELKOR LINEAR SCREEN BROCHURE

Worldwide interest in revolutionary Delkor Linear Screens

By

HENDRIK VORSTER

EDITOR-IN-CHIEF

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Worldwide interest in revolutionary Delkor Linear Screens

The story of a recent achievement in the mining field which claims to solve an age-old problem in metallurgical recovery.

By HENDRIK VORSTER

A new screening unit used in metallurgical processes has, over only one year, proved itself so successful that the company marketing and installing the equipment, Delkor Technik, has received orders for some 30 units to the value of about R2,5-million.

The Delkor linear screen (DLS) is a joint development between Anglo American and Delkor Technik.

With the use of the carbon in pulp system in gold recovery, wood chips and fibre derived from the timber supports used in mining proved to be difficult to remove efficiently using normal vibratory screens. Wood chips/fibre accumulate in the adsorption tanks, reducing the throughput rate.

Dr Ray Davidson at the Anglo American Reserch Laboratories, sought to solve the problem and at the end of 1984, in conjuction with Delkor, pioneered the use of a linear cloth screen to remove the wood fibre.

A prototype linear screen was installed at the Afrikander Lease Division of Vaal Reefs Gold Mine at Klerksdorp to remove wood fibre and other oversize material from the feed to the carbon adsorption plant.

"The screen solved a major problem. It was found to effectively remove more than 98 percent of the wood fibre without any sign of blinding in the fine apertures of the screen itself," Mr Phil Mostert, consulting metallurgist for the Anglo American Corporation, said.

"Without this screen we were experiencing problems with accumulation of wood chips/fibre in the absorption section of CIP plants."

Mr Mostert said that a Delkor linear screen unit would be installed on the new No 1 Shaft complex gold plant at the Western Deep Levels Gold Mine, Carletonville.

At Sallies, where a linear screen had been installed, it was found remarkably effective for removing the majority of the ash from the sand from which gold is being reclaimed.

DR RAY DAVIDSON

Ash has the disadvantage of absorping gold and reducing gold recovery.

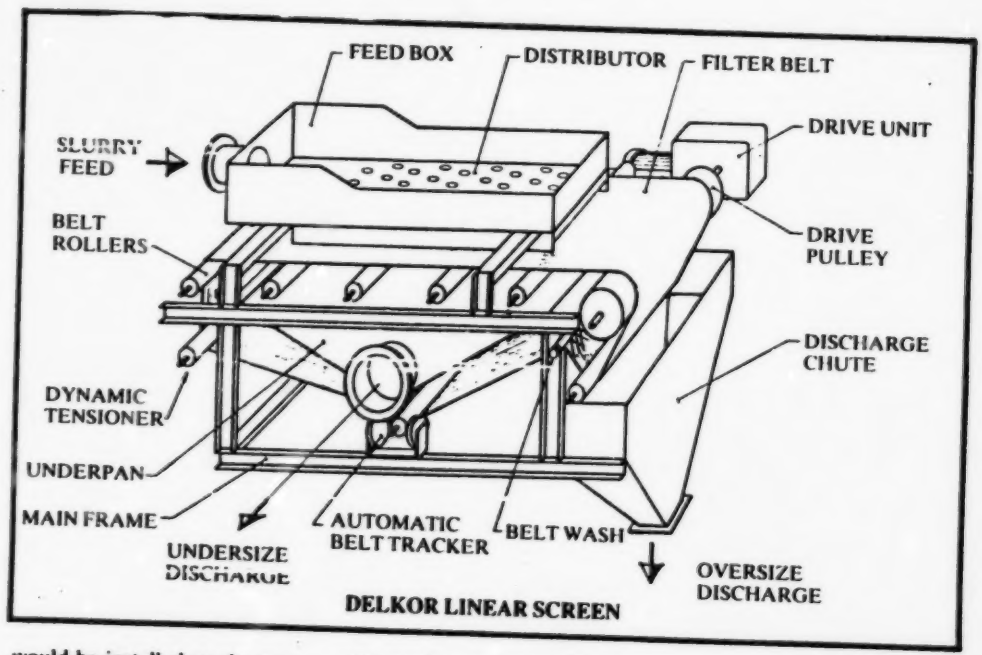
Mr Mostert said the screen could also possibly improve the recovery of, say, tin in tin recovery plants.

It represented a breakthrough and there was no reason why other countries of the world should not also benefit by using such screens.

The Delkor Linear Screen comprises a coarse monofilament screen cloth supported on cloth rollers and driven by a head pulley coupled to a variable speed drive unit.

Slurry is fed through a distributor on to the moving monofilament cloth. The undersize material drains through the cloth by gravity and is collected in the underspan.

The wood fibre and oversize material retained on the screen is discharged at the drive pulley, using a belt wash spray.



DELKOR LINEAR SCREEN

The belt wash spray ensures a continuous, self-cleaning screen, and by adjusting the weave configuration of the screen cloth, the cut point for oversize removal can be easily varied.

The prototype unit at Afrikander Lease Division of Vaal Reefs Gold Mine — a 6 sq m unit — has been operating practically trouble-free since the first week of January, 1985. It replaced a conventional vibrating screen having slotted apertures of 0,5mm.

Over a period of two weeks the concentration of wood fibre measured after the thickening section reduced from ,075 gm/l to ,002 gm/l wood fibre in the pulp.

Apart from achieving its objective as an efficient machine for the removal of woodchips /fibre, the DLS proved to have numerous further advantages:

- It operates without vibra-

tion, eliminating the need for expensive civil and structural construction common in conventional mill buildings;

- It eliminates common stress cracking problems encountered with vibratory screens;
- The noise level is markedly reduced due to the absence of vibration;
- Power consumption of the unit is a small fraction of that required for vibrating screens;
- Availabilities in excess of 97 percent have been recorded on most installations:
- High throughput rates per unit screen area are possible; and
- Simplicity of operation and open design have shown benefits in very low maintenance costs on the DLS
- The cloth is very simply and readily replaced.

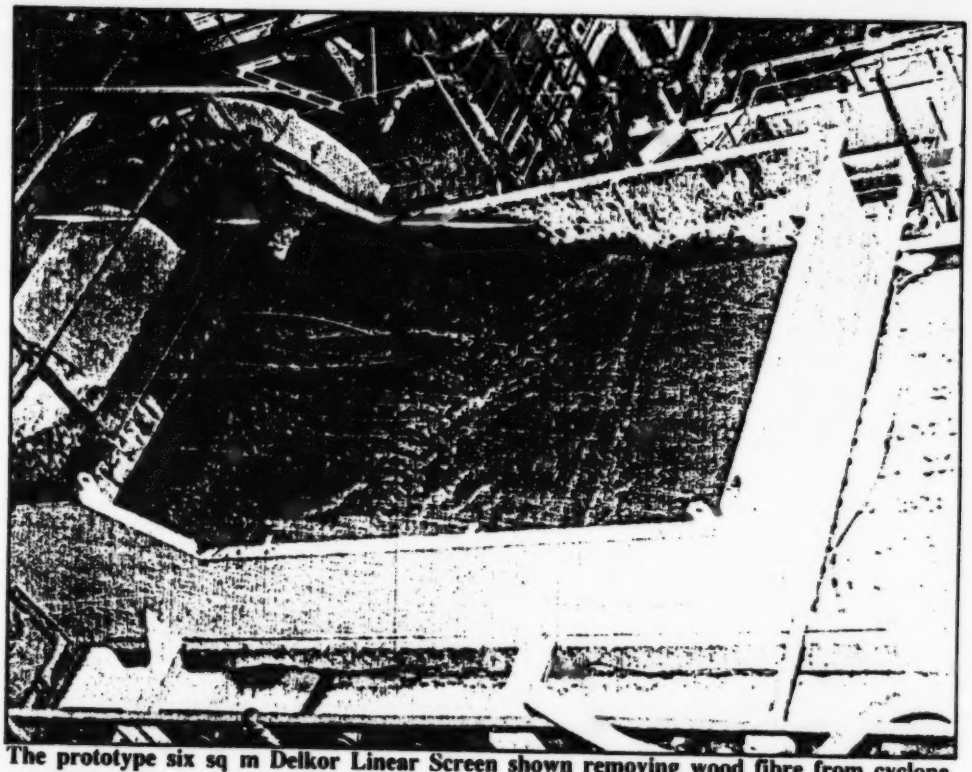
Mr Peter Sampson, sales manager of Delkor Technik, said that since the successful commissioning of the prototype at Afrikaner Lease, great interest had been shown in the unit by representatives in the mining industry and among major orders placed for new projects and replacement of conventional equipment were:

- East Daggafontein, 8x20sq m DLS
- Western Deep Levels, 2x12sq m DLS
- Harmony Gold Mine, 4x12sq m DLS
- Newmont Mining (Australia), 4x 6sq m DLS
- Ergo (Simmergo)

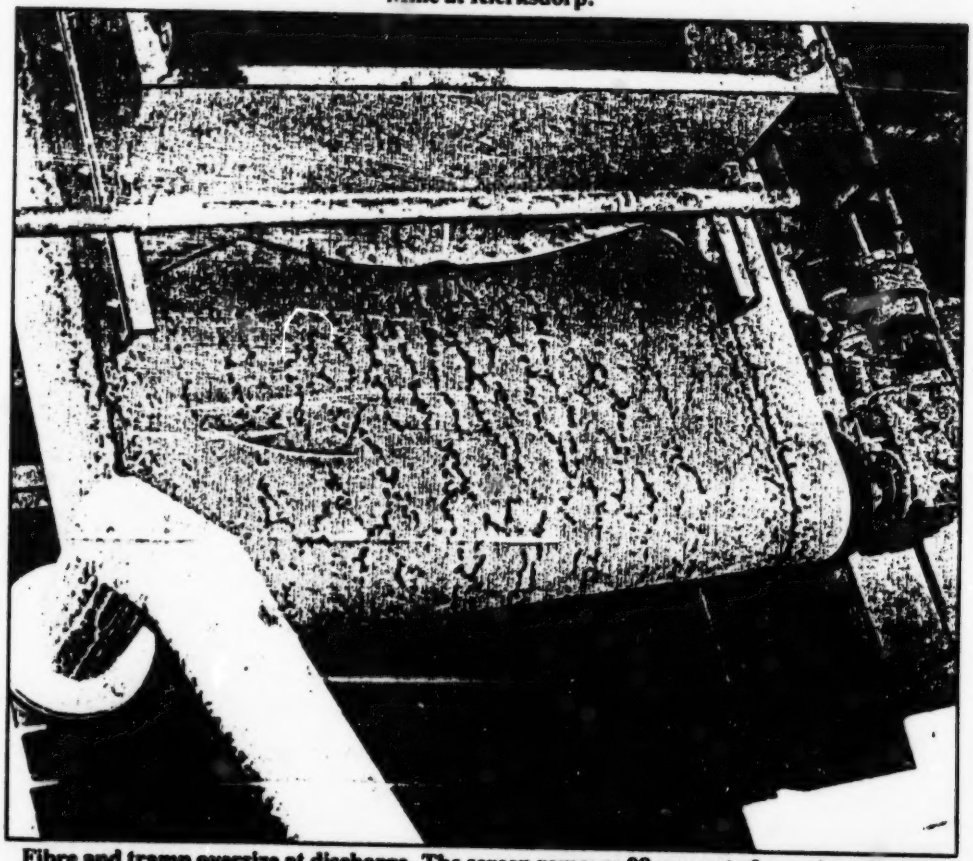
The DLS has been patented worldwide by Anglo American Corporation and is sold by Delkor Technik under licence on a worldwide basis. The standard product range is 0,5sq m, 1,5sq m, 3sq m, 6sq m, 12sq m and 20sq m.

The DLS has already proved to be extremely flexible with units being applied to cyclone overflow, thickener underflow, plant sands feed, carbon scavenging and resin bead screening.

Intensive research programmes are continuing between AAC and Delkor to investigate the use of the machine at cut points down to 100-mesh for use in milling circuits.

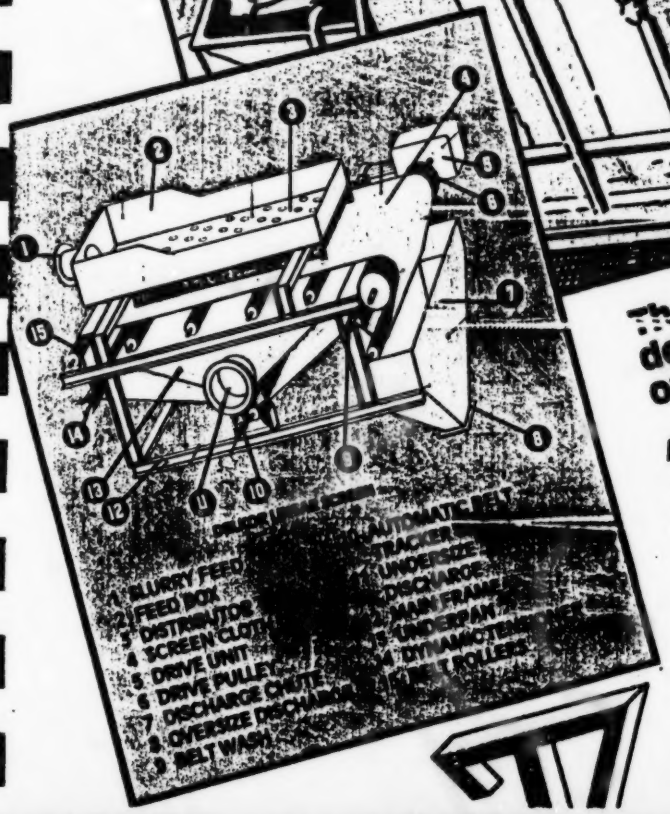


The prototype six sq m Delkor Linear Screen shown removing wood fibre from cyclone overflow during commissioning of the screen at Afrikander Leases Division of Vaal Reefs Gold Mine at Klerksdorp.



Fibre and tramp oversize at discharge. The screen removes 98 percent of oversize material.

Screening problems? You can now remove 98% of tramp oversize with the Delkor Linear Screen.



The Delkor Linear Screen is a unique system designed to remove coarse solids, tramp oversize and wood fibre from a slurry.

ADVANTAGES OVER OTHER SYSTEMS INCLUDE:

• Incomparable efficiency — 98% removal of tramp oversize • No vibration at all • Up to 90% reduction of power consumption compared with conventional machines • Elimination of scaling • Silent operation • 99% availability achieved with prototype • Low installation and maintenance costs.

DELKOR

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